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RELIABILITY AND IMPROVEMENT WITH REPEATED
PERFORMANCE OF THE SJOSTRAND WORK CAPACITY TEST

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
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by

Edward W. R. Zahar

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APPROVAL SHEET

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Reliability and Improvement with Repeated Performance of the Sjöstrand Work Capacity Test", submitted by Edward W. R. Zahar in partial fulfilment of the requirements for the Degree of Master of Arts.

ABSTRACT

Thirty-eight male students from the physical education classes at Strathcona Composite High School were selected as subjects to determine if repeated administration of the Sjöstrand test resulted in improved physical work capacity scores and if there was any effect on the reliability of the test. The hypothesis was that the mean scores from repeated tests would be equal.

The Sjöstrand test was administered to each subject at the same time on the same day of each week for six successive weeks. The test was conducted on a Monark Bicycle Ergometer in three consecutive six minute periods each at a higher work load. The heart rate was recorded each minute throughout the test. Work capacity was determined from a regression analysis. The work capacities were then punched on IBM cards and Pearson Product-moment correlation coefficients as well as partial correlations were calculated by the IBM 7040. An analysis of variance and Duncan's New Multiple-Range test completed the basis for the statistical analysis.

The results include mean physical work capacities of 943, 973, 994, 1039, 1018, 1003 Kilopond-Meters per minute. Upon applying the two-way analysis of variance for correlated samples and Duncan's New Multiple-Range test it was found that there were statistical differences between the following tests: 1 - 4, 1 - 5, 1 - 6, and 2 - 4 at the 99.5% protection level; while

at the 95% protection level statistically significant differences occurred between tests 1 - 3, 1 - 4, 1 - 5, 1 - 6, 2 - 4, 2 - 5, and 3 - 4.

The first test-retest reliability coefficient was .886. The succeeding test-retest reliabilities were: .894, .841, .877, and .947.

Within the limits of this study the following conclusions have been made:

1. For the population studied, the Sjöstrand test is a highly reliable measure of physical work capacity.
2. Improvement occurs upon repeated testing of subjects, but it could not be said whether this improvement was due specifically to learning, training or some other effect.
3. Apprehension decreased the value of the first test work capacity.
4. Evidence was secured which supports the effect of ambient temperature on the shifting of the pulse rate/work curve to raise or lower work capacity.
5. Low but significant correlations were found between work capacity and age, height, and weight.
6. An attempt to separate intra-individual and inter-individual differences on the basis of the test-retest variances met with only partial success because of no adequate means of establishing variable measurement error.

7. Correlations between first and final work capacity scores with raw improvement scores were not significant; but were significantly different ($p = .01$) from each other.

8. The statistical partialling out of age, height and weight tends to reduce the reliability coefficients only slightly and is not necessary for relatively homogeneous samples, especially if the time interval between tests is short.

9. Pre-exercise heart rates have low negative correlations with work capacity ($p = .05$).

10. The mean pre-exercise heart rate on the first test correlated well with the first and second work load heart rates ($p = .01$) but non-significantly with the third work load heart rate.

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To Doreen, my wife, I extend my undying love through eternity for the patience and understanding which you were often called upon to exercise during the past year.

For the love, moral support and sacrifices which my parents have extended to me throughout the years may I pay particular acknowledgement at this time, and pledge to you the eternal love of a grateful son.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction. Exercise physiologists usually agree that performance of hard physical work is related to the ability of the respiratory and cardiovascular systems to actively transport oxygen to the tissues and for the tissues to utilize that oxygen (6, 31, 39, 62). This is called maximal oxygen consumption, aerobic capacity or physical work capacity (6, 39, 40, 54, 62, 67). When measuring maximal oxygen consumption two general types of tests are commonly used: (a) maximal tests and (b) submaximal tests. Wahlund (67) has an excellent review of these tests up to 1948. In North America the treadmill has been the more favored testing apparatus for maximal tests (50,62); while use of the bicycle ergometer has been more limited. Yet in Europe the bicycle ergometer is a well established research instrument for both maximal and sub-maximal tests (1, 2, 11, 58, 66) and it is claimed that the bicycle ergometer has many advantages, such as:

- (a) the apparatus is not costly (12)
- (b) the apparatus is not bulky (12)
- (c) the apparatus is easily moveable
- (d) the testing period is short
- (e) it is a practical apparatus for field work (67)
- (f) work loads may be controlled as accurately as those on a treadmill (67)

- (g) oxygen consumption is directly related to work load and mechanical efficiency among individuals is only slightly different (67)
- (h) various parameters are easily measured during work on the bicycle ergometer, e.g., blood lactate (28, 67)
- (i) hydrostatic changes in blood play only a slight role (67).

The treadmill is the preferred instrument for precise research by many investigators, notably Ericksen et al. (28) because the work load on the treadmill is fixed and does not require the subject to keep time, nor does the subject need to learn a new skill or relearn an old skill as is often the case with the variable load type bicycle ergometer. Ericksen et al. (28) also state, "A larger total energy expenditure is obtainable on the treadmill ... (and) ... the work load is automatically adjusted to body size."

Both the treadmill and the bicycle ergometer have distinct advantages as research tools for measuring maximal oxygen consumption. The use of submaximal work loads to obtain physical work capacity or to predict maximal oxygen intake is based on the linear relationship of pulse rate to work load over a wide range of values (13, 57, 67). Sjöstrand (57, 58, 59, 60) has found that there is a close correlation between exercise intensity and stroke volume at a pulse rate of 170 beats per minute. In the Sjöstrand submaximal test a line is established empirically for each subject on the basis of two or three "points" plotted on a graph of heart vs. work

load and the best fitting straight line is extrapolated to give a work load value for a heart rate of 170 beats per minute. This value is then called the subject's physical working capacity. Astrand and Ryhming (3, 4, 8) using a similar test have constructed a nomogram which predicts maximal oxygen intake.

Astrand (4, 5) and Rodahl et al. (55) have suggested that maximal oxygen intake is the best measure of physical fitness available. The difference between physical work capacity and physical condition is ably pointed out by Astrand (5 : 140):

Work capacity is a synthesis of aerobic and anaerobic capacity, mechanical efficiency and physical condition whereas physical condition states how the circulation, respiration, muscles etc. are fit for hard work of long duration. The heaviness of the work must be related to the individual's work capacity. Thus, working capacity is quantitative and physical condition is more qualitative.

This distinction is not consistent throughout the literature. It is apparent that "physical fitness", "physical condition", "physical work capacity", and "maximal oxygen consumption" are not synonymous. However they are, to some extent, similar. Wahlund (67), using the Sjöstrand test, reported a mean oxygen consumption at a pulse rate of 170 which was 80% of maximal oxygen consumption. Cumming and Danzinger (20) found a value of 73% for the same measure. An attempt was made to correlate working capacity and predicted maximal oxygen intake by de Vries and Klafs (23) using sixteen subjects, six submaximal tests and one maximal test on a bicycle. The Sjöstrand test gave a correlation of .877 with maximal oxygen

uptake per Kg. when expressed in KPM/Min/Kg. and of .766 when expressed as KPM/Min/M², both figures being significant at the .01 level. These were among the highest correlations found. They concluded that the Sjöstrand test gave one of the highest predictive values.

A study which compared the Astrand-Ryhming "predicted" value of maximal oxygen intake to that found directly by several maximal treadmill tests was conducted by Glassford et al. (31). He tested 24 subjects between the ages of 17 and 33 years and although he found that the modified Astrand Bicycle Ergometer Test gave significantly lower maximal oxygen intake values ($p = .05$) than the other tests, the relation between the Astrand nomogram values and any other value obtained by direct measure was as good as the relation between any two direct measures.

Cumming and Danzinger (20 : 204) have reported that "... the validity of the pulse rate method in determining working capacity was confirmed by the oxygen consumption studies." Although they give a graph of this relationship they do not fit a regression line to the data or give any figures to support their statement.

This study is timely because the results and part of the procedure used will bear directly upon the currently planned Canadian Association for Health, Physical Education and Recreation Research Committee's study of work capacity. This study is designed to investigate the possibility of a practice or learning effect on the Sjöstrand test and how this might in turn effect the reliability of work capacity.

It is suggested that Canadians do not use the bicycle as much as many other nations. This observation, in turn, leads to a questioning of the reliability of the Sjöstrand test for Canadians. It also raises the possibility of a learning or training effect. These questions can only be answered on the basis of experimental evidence.

The Problem. In order to obtain a portion of the answer to the questions raised it is the purpose of this study to investigate if there is improvement in physical work capacity over six trials at intervals of one week, as well as to determine the reliability of the Sjöstrand test under these conditions.

Subsidiary Problems. Subsidiary to the main purpose of this study are several other problems which will be investigated concurrently:

- (1) The effect of the average pre-exercise pulse rate on the first and succeeding work load steady state pulse rates for the first test only.
- (2) Determining factors which correct the work load for the actual number of revolutions done in the work period.
- (3) Determining the inter- and intra-individual variability of the steady state heart rates as well as the variability of the working capacity.

Limitations.

1. This investigation was limited to 38 Edmonton boys taking Physical Education at the Strathcona Composite High School.
2. Work capacity was the only physiological variable to be investigated. It, in turn, was dependent upon heart rate and corrected work load for the purposes of this study.
3. The test is to be administered six consecutive times to each subject at intervals of one week.
4. Times of succeeding visits to the field laboratory were the same for each subject on each occasion.
5. No control was placed on the subject's activity on the day of the test except that he was to refrain from strenuous physical exercise for at least one hour prior to the test and the subject was not to eat or smoke, if possible, in the hour and a half before the test.
6. Temperature and humidity were not controlled.
7. Only the parameters stated in the problem and subsidiary problems were considered.
8. This study was further limited by the statistical analysis used.
9. Further limiting factors included: accuracy of work load guage, instrumental errors and observational errors.

Assumptions.

1. The transition to higher work loads was made almost instantaneously and without interruption.
2. The maximum heart rate at which work may be performed adequately was arbitrarily set at 170 beats per minute for this study.
3. For those individuals who had not reached a heart rate of 170 beats per minute a linear relationship between work load and pulse rate was assumed and their working capacity was determined by extrapolation of the regression line.
4. For those individuals who exceeded a pulse rate of 170 beats per minute prior to the completion of the Sjöstrand test either (a) if the subject did not complete the higher work load, the work load before this arbitrary limit will be used to calculate the working capacity, or (b) if he completed the work load, then a process of interpolation was used.

Definitions.

Work Capacity. Work capacity (PWC_{170}) has been defined as the working intensity in KPM per minute which the subject could perform at a pulse rate of 170 beats per minute (13). It is obtained by using a stepwise increase in work load until a heart rate of approximately 170 is attained and then utilizing the approximately linear relationship between pulse rate and work load to determine, by intra- or extrapolation, a value of the PWC_{170} .

Work Load. The calibrated frictional force applied to a friction belt which the subject must overcome to continue cycling at a rate of 60 cycles per minute and is a product of the resistance and rate.

Maximal Oxygen Intake. For normal subjects a linear relationship between progressively increasing work loads and oxygen consumption may be demonstrated up to a certain point, at which maximal oxygen intake per unit of time is reached and even though the work load may be increased the oxygen intake either remains constant or declines (50).

Kilopond Meter. The force acting on one kilogram mass at the normal acceleration of gravity.

Intra-Individual Variance. The variance attributable to biological variation in the functional status of the individual.

Inter-Individual Variance. The variance attributable to true differences between individuals.

Error Variance. The variance due to variable error in instruments, observational errors and the like.

CHAPTER II

REVIEW OF THE LITERATURE

History of the Sjöstrand Test. In 1947 Sjöstrand (57) reported findings on the physical work capacity of 20 workmen employed in an ore smelting works. The test was different from the test currently employed but the basic features were present. Thus the work loads employed were 300, 600, 900 and occasionally 1200 Kgm/Min. for a ten minute interval at each work level except the last, which was either six or four minutes. This work was continued at a rate of 300 M/Min. until the heart rate was either greater than 175 beats per minute or the increase between the first determination and the last was more than 10 beats per minute. When this critical level was reached the next lower load was then considered the highest which could be maintained without signs of insufficiency of respiration and circulation. In this same article (57) Sjöstrand states that about two thousand work capacity tests of a similar type were carried out at the Carolina Hospital, but he does not indicate any earlier reports of this type of test in the literature. Bengtsson (12) indicates that these original tests referred to by Sjöstrand were developed in 1943.

Wahlund (67) tested 469 adult males on a bicycle ergometer starting at a work load of 300 or 600 KgmM/Min. and increasing the work load every $6\frac{1}{2}$ minutes by 300 KgmM/Min. until the subject could not continue or work at 1200 KgmM/Min. was done. Pulse rates

were determined at two minute intervals throughout the test. Lung ventilation, oxygen consumption and respiratory rates were determined at each work load. Wahlund concluded that it was possible to estimate the limit of cardiac output by studying the individual subject's pulse curve. He set the maximum heart rate at which work may be performed adequately at 170 beats per minute. If this heart rate is not reached he proposed that use be made of the known linear relationship between work load and heart rate to determine the work load which could be done at that heart rate. This is commonly called Physical Work Capacity 170 and is usually abbreviated as PWC_{170} . Wahlund also examined respiratory rate and came to the conclusion that it was less stable than pulse rate under work.

Wahlund concluded that the bicycle ergometer was a practical testing instrument and gave a list of it's advantages. He also expressed the opinion that those factors which limit work capacity are neuro-muscular, circulatory-respiratory and psychological. For work continued until exhaustion, he felt that anaerobic work and mental stamina were being measured. The Sjöstrand test is sometimes referred to as the Wahlund test in the literature.

In 1949, Kjellberg et al. (42) made a further modification of the Sjöstrand test. This modification consisted of a further shortening of the time pedalled at each work load to six minutes and the extrapolation of the pulse curve to 170, if that pulse rate was not achieved. Otherwise the testing procedure was as outlined by Wahlund.

Bengtsson (12) made further refinements in the Sjöstrand test in 1956 when testing 76 children and 38 adults. Firstly, he re-defined work capacity as the work performed on a bicycle at a pulse rate of 170 beats per minute, provided that heart rate has reached a relatively steady state and the frequency of respiration does not exceed a given value depending on age and weight. He used an hydraulic constant work load type bicycle ergometer made by Belmag and another using a D.C. generator on which the subjects pedalled at a rate of 45 to 60 revolutions per minute. He attempted to adjust work loads so that the heart rates would be approximately 125-130, 140-150 and about 170 beats per minute for each successive work load. He also utilized the concept of "steady state pulse rate", but this concept has not been applied extensively to the Sjöstrand test. Bengtsson also felt that heart rates of over 170 were less reliable than those near 170.

Adams et al. (2) used the Sjöstrand test to study 243 normal white school children in California. The ages ranged from 6 to 14 years for both boys and girls. The subjects worked on an electric constant work load type bicycle ergometer at a rate of 60-70 rev/min. at three different and consecutive work loads, each of which lasted for six minutes. Heart rate was determined stethoscopically for 30 seconds every fourth and sixth minute of each work load. They attempted to schedule the work loads for each subject so that the first work load produced a heart rate of 100 to 120 beats per minute, the second produced 120 to 140 beats per minute and the last 150 to 170 beats per

minute. They also gave the work loads normally followed for subjects falling within certain weights. Work capacity was obtained graphically.

In a second study conducted by Adams et al. (1), 196 Swedish children of both sexes, ages 10, 11 and 12 years from city and country were studied. In this experiment another modification of the Sjöstrand test occurred, vis., they cut down the number of consecutive work loads from three to two. They tried to obtain heart rates of about 140 beats per minute in the first and approximately 170 in the second. Heart rate was recorded both stethoscopically and on an electrocardiogram every two minutes throughout the test. Again work capacity was determined by plotting the heart rate vs. work load graphically and determining the work load at a pulse rate of 170 beats per minute.

In recent years the Sjöstrand test has been used in Canada. Cumming and Cumming (19) and Cumming and Young (21) followed the same procedure as Adams in the California study (2). In another study Cumming and Danzinger (20) followed a procedure similar to the second study by Adams (1). In all of these studies an electrically braked bicycle ergometer by Holmgren and Mattson was used. It is claimed that this type of bicycle ergometer allows accurate setting of the work loads over a wide range of values and is independent of minor fluctuations in pedalling rate.

Another study which utilized only two consecutive work loads was conducted by de Vries and Klafs (23). They used work loads of 450 and 900 KpM/Min. The subjects pedalled at a rate of 60 rpm per six minutes at each load.

Physical Working Capacity and Maximal Oxygen Intake.

Although physical working capacity may be investigated using many different tests, it is usually expressed in three different ways (67) viz., work load at a given pulse rate, pulse rate at a given work load, or as maximal oxygen intake. For submaximal bicycle ergometer studies of work capacity the usual method of expression has been the work load at a given pulse rate.

Physical work capacity is a measure of the individual's capacity for doing hard muscular work (55, 67). This in turn has been described (8) as probably the best measure of a person's physical endurance and gives a good indication, when divided by weight, of physical fitness. If physical fitness is restricted to the ability of the individual to do heavy work, then Hettinger et al. (40) would seem to agree, especially so if maximal oxygen intake were substituted for work capacity. Many other investigators (6, 7, 19, 59, 62) have agreed with this general position.

But physical work capacity and maximal oxygen consumption are not synonyms. Mitchell, Sproule and Chapman (50) indicate that maximal oxygen intake measures are, for a normal person, an index

of maximal cardiovascular function if pulmonary function is normal. Taylor et al. (62) point out very clearly that when an investigator examines work capacity he investigates work load at a pre-determined minute pulse rate, while the investigator examining maximal oxygen intake measures cardiac capacity. For work capacity submaximal work loads are used, but for maximal oxygen intake the subject works close to a maximal work load. Wahlund (67) demonstrated that a heart rate of 170 beats/min. physical capacity is approximately 80% of the value of maximal oxygen intake. Others (1, 2, 15, 19, 20, 57) support this position.

However for purposes of this study it should be recalled that work capacity and maximal oxygen intake are related to some extent, and so it will be necessary to look at factors affecting one as though it may affect the other until there is more research to demonstrate otherwise.

Variation in the Maximal Oxygen Intake. Inter-individual variation is a characteristic of any measure, it can be demonstrated to some extent by the range of values found for the item being examined. For maximal oxygen intake this range is extensive. Astrand found a value of .74 liters per minute for a four year old girl (5). At the other end of the range Robinson et al. (54) found a value of 5.35 liters per minute for an outstanding middle distance runner. However it should

be noted that measures of maximal oxygen intake and work capacity correlate with age (2, 3, 4, 45, 52, 54) and this would reduce the importance placed on the figures just given. When the range at a specific age is examined it is still large, indicating a wide inter-individual variability.

Henry (33, 34, 35, 36) has demonstrated a method of statistically separating inter-individual variance from intra-individual variance on the basis of the reliability coefficient:

$$r_{11} = \frac{s_t^2}{s_t^2 + (s_i^2 + s_e^2)/n}$$

where s_t^2 is the inter-individual variance, s_i^2 is the intra-individual variance for single trials, s_e^2 is the measurement error variance, and n is the number of trials averaged to form an individual's score. This analysis has not been used on any of the data reviewed herein but is used in the analysis of the data obtained in this paper.

Intra-individual variability has been noted by Astrand and Saltin (9) when they point out different values for the maximal oxygen intake for the same subject at different grades on a treadmill when speed was constant.

Newton (51) administered the Balke test (modified), the Cureton "all-out run", a treadmill test adjusted to the individual and a bicycle ergometer test to seven subjects aged 19 to 70. The data was not analyzed statistically but he concluded that the maximal oxygen intake values were lower on the bicycle ergometer than on the treadmill.

Sixteen subjects were given a battery of tests by de Vries and Klafs (23) which included a modified Mitchell, Sproule and Chapman treadmill test and six submaximal tests, including the Sjöstrand test and the Astrand-Ryhming Predictive test. They found significant correlations ($p = .01$) between the Mitchell, Sproule and Chapman test and: (a) the Sjöstrand test expressed in kilopond meters per minute per kilogram of body weight ($r = .877$), (b) the Harvard Step test in l/min/kg ($r = .766$), (c) the Sjöstrand test in kpm/min/M² ($r = .736$), and (d) the Astrand-Ryhming test in l/min. ($r = .736$). On the basis of these results the authors then conclude that since the Astrand-Ryhming test is shorter and uses only one work load, there is no advantage in using the Sjöstrand test. Although this difference is not significant, it should be noted that the Sjöstrand test has a higher correlation (.877) and thus accounts for more of the variability (77%) than the Astrand-Ryhming test (.736 and about 55% respectively) does, and so should be a better predicting instrument.

Binkhorst and van Leuween (14) compared three bicycle ergometer methods of obtaining maximal oxygen intake on four subjects. The tests were the Astrand test, a continuously increasing work load type test, and one in which the work load was increased to a steady state pulse rate of 140 to 150 beats per minute. In the later two tests the subjects continued to exhaustion. No significant differences were found between

the means or peak values. But they did conclude that maximal oxygen could be determined by the bicycle ergometer by continuously increasing the work load in one session.

Hettinger et al. (40), using 28 subjects between the ages of 20 and 30 years, found statistically significant ($p = .05$) differences for predicted values and actual values of maximal oxygen intake. This was on the basis of means of 2.62 l/min. predicted and 2.38 l/min. actual maximal oxygen intake. They concluded the difference was accountable because the nomogram was constructed on the basis of well-conditioned athletes.

Glassford et al. (31) used an experimental group of 24 male subjects to compare values on four maximal oxygen consumption tests. They found that the mean values for maximum oxygen intake on the Mitchell, Sproule and Chapman, Taylor et al. and the modified Astrand-Ryhming Nomogram were significantly ($p = .05$) larger than the mean for the modified Astrand Bicycle Ergometer test. These results tend to support those of Hettinger et al. (40) since they used a bicycle ergometer to determine maximal oxygen consumption.

Forty-eight males were tested by Baycroft (11) to evaluate the ability of the Astrand-Ryhming Nomogram to predict maximal oxygen consumption. The Nomogram correlated significantly ($r = .67$, $p = .01$) with the Mitchell et al. test, as well as correlating .62 with the Astrand Bicycle test.

The Reliability and Validity of the Sjöstrand Test.

There are two ways of establishing the validity of the Sjöstrand test. The first is to compare it to direct measures of maximal oxygen intake, and the second is to use a comparison between indirect measures.

Wahlund (67) concluded that provided the subject was not at the point of exhaustion, it was possible to obtain an estimate of oxygen consumption at different loads without making a special determination. He states (67 : 32), "Oxygen consumption is indirectly estimated from work load within a range of $\pm 8\%$ in 2/3 of the cases." However, he also cautioned that for more accurate measurement maximal oxygen intake should be measured directly.

As has been stated before, de Vries and Klafs (23) studied the correlation of the Sjöstrand test to a modified Mitchell, Sproule and Chapman test. They found that maximal oxygen intake correlated at the $p = .01$ level with the Sjöstrand test ($r = .703$) and that oxygen intake/kg correlated to the Sjöstrand test expressed in kpm/min. ($r = .573$, significant at the .05 level), in kpm/min/M² ($r = .762$, $p = .01$), in kpm/min/kg ($r = .877$, $p = .01$). This would tend to indicate that fairly adequate prediction of maximal oxygen intake could likely be made from the Sjöstrand test, especially if weight is partialled out. It should also be noted that they found a correlation of $r = .736$ ($p = .01$) between the Astrand-Ryhming prediction and maximal oxygen intake.

Although Cumming and Danzinger (20) do not give any figures they report that there was no significant difference between working capacity means for 19 boys and 22 girls when retested. This amounts to a crude form of test - retest reliability.

Age and Physical Work Capacity. It is generally agreed in the literature that work capacity gradually increases with age (1, 2, 4, 5, 12, 19) up to a peak and then gradually declines (25, 61). Cullumbine (18) tested 7000 Ceylonese from age 10 to well into adult life. For the male sample there was no significant change with respect to heart rate vs. exercise until the age of 14, when the fitness level dropped suddenly, remained constant till 16 and then began to rise to a maximum between 21 and 25 years of age. In females the pattern was slightly different, as the fitness level decreased from age 10 to 14 ($p = .001$), and the maximum was at age 31 to 35 years. These changes seem to correspond to puberty.

Bengtsson (12) found that the largest variation in terms of standard deviation was in children under 10 years. He also observed that work capacity rose steadily between the ages of 5 and 14 years. The 5 and 6 year olds had a work capacity of 37% of their capacity at age 13 or 14 years. Similarly at ages 7 to 9 the relation was 50% and at 10 to 12, 83% of the work capacity at 13 or 14. In comparison to adults the percentages were 20, 28, and 44 respectively.

Astrand (4, 5) has reported findings somewhat similar to those of Bengtsson (12), except that he found the greatest variation in children in the age range 12 to 15 years.

Durnin et al. (25) and Strandell (61) have demonstrated that older men have lower maximal oxygen consumptions and work capacities. Durnin et al. also demonstrated an increase in energy output for the same work load as compared to younger men. These findings tend to indicate a decline in work capacity in older men.

Sex Differences and Work Capacity. Bengtsson (12) reported differences in the pattern of development of work capacity for boys and girls as was outlined above (ibid : 12). This has been supported by several other writers, notably, Adams et al. (1), Adams et al. (2), Cumming and Cumming (19), Cumming and Danzinger (20), and Astrand (4, 5) to name a few. Astrand (4) and Bengtsson (12) reported that up to the age of 15 there were no significant differences in work capacity based on sex but later the males were about 30% higher than females.

Body Weight and Work Capacity. Many researchers have pointed out the relation of body weight to work capacity and maximal oxygen consumption (1, 2, 23, 52, 54, 74). Cumming and Cumming report (19) a correlation of .897 for boys and .696 for Winnipeg girls of weight to working capacity.

De Vries and Klafs (23) report a correlation of .877 between the Sjöstrand test and a modified Mitchell, Sproule and Chapman test of maximal oxygen intake when weight is partialled out. Adams et al. (2) found a correlation of .81 for boys and .77 for girls when comparing log weight to physical work capacity of California children. But in another study Adams et al. (1) found correlations of between .27 and .65 for the same measures on Swedish children. This effect on the correlations may be related to the homogeneity or heterogeneity of the sample.

Height and Work Capacity. For boys a correlation of .83 was found between log height and work capacity by Adams et al. (2); in the same study they found a correlation of .76 on these parameters for girls. However, in Sweden they (1) were not able to obtain such high correlations on these parameters (.30 to .69). In Winnipeg, Cumming and Cumming (19) demonstrated correlations of .865 for boys height and .658 for girls height with respect to work capacity on the Sjöstrand test.

Surface Area and Physical Work Capacity. Adams et al. found the following correlations between log surface area and Sjöstrand's measure of work capacity: in California (2) girls $r = .80$, boys $r = .81$; Sweden (1) city girls $r = .30$, country girls $r = .68$, city boys $r = .37$, country

boys $r = .55$. For boys and girls Cumming and Cumming (19) obtained correlations of .904 and .683 respectively between surface area and work capacity. The correlation between the Sjöstrand test and the modified Mitchell, Sproule and Chapman expressed in kpm/min/M^2 and maximal oxygen intake per kilogram was observed by de Vries and Klafs (23) to be .762, which was significant at the .01 level.

Emotion and Pulse Rate. Bengtsson (12) felt that mental factors governing emotion would play a rather insignificant role in continuous heavy work. Others (47, 57) question whether mental factors would have any significant effect on submaximal work. Astrand (7) feels that since oxygen uptake is regulated within such narrow bounds, this measure would be resistant to changes in mental state of the subject. Taylor et al. (63) noted that submaximal pulse rates were significantly higher when the subject first took the test than on retesting. Rowell et al. (56) compared groups between which there was no significant difference before training and then after training found that with the stress of catheters there was a 6% ($p = .001$) greater underestimation of maximal oxygen consumption using the nomogram.

Temperature and the Work Rate Curve. Williams et al. (70) demonstrated on three Bantus acclimatized to heat that work in a hot environment moves the pulse rate/work curve to

the left but maximal pulse rate is not altered. Rowell et al. (56) demonstrated that in unacclimatized men maximal oxygen intake could be increased by as much as 2 liters with no change in maximal pulse rate. Work done at 65° F. displaced the curve to the right. Taylor et al. (62, 63), Erickson et al. (28) and Buskirk et al. (16) recommend a room temperature of $78 \pm 4^{\circ}$ F, as standardized experimental temperature.

Food Ingestion and Pulse Rate. While a small meal i.e., one of 750 calories, has no overt effect on maximal oxygen intake (62), a large meal does (46, 63). Lundgren (46) demonstrated that breakfast changed the pulse rate by 18 beats per minute at an oxygen consumption of one liter per minute. Taylor et al. refer to another study (op. cit. 63 : 705), unpublished, in which it was demonstrated that the pulse rate increased from 132 to 144 beats per minute at an oxygen intake of two liters per minute after a 1000 calorie meal. The effect had not dissipated completely after one and one half hours.

Learning on the Bicycle Ergometer. Astrand (6) has stated that learning is negligible on the bicycle ergometer. In contrast to this position, Krogh and Lindhard (44) have stated that in areas where bicycle riding is not popular subjects may improve substantially in mechanical efficiency with practice.

CHAPTER III

METHODS AND PROCEDURE

Selection of Subjects. Forty-eight healthy male subjects were selected from the physical education classes in Strathcona Composite High School. The age range was from 15 years, 1 month, to 19 years, 8 months, with a mean of 16 years, 4 months. The subjects were selected on the following basis:

(a) The nature of the experiment was explained to each physical education class on April 12 and 13, 1965, by the investigator.

(b) Each student who expressed a desire to take part in the experiment was given a consent form (Appendix B) which was signed by his parent(s) and which gave his and/or her consent for the boy to participate in the experiment.

(c) These forms were collected by the investigator on April 14 and 15, 1965, during the regular physical education classes. A random draw was made in each class from those forms turned in. This draw was made by the physical education teacher, one pupil and the investigator in that class. There were six forms drawn from each class until 48 subjects were selected. Of the original 48 subjects, 38 met the conditions of the experiment, the remaining ten were deleted from the study; mostly for failure to attend each testing session.

Test Period. The experiment was carried out from April 28 to June 14, 1965. The data were collected Monday through Thursday inclusive of each week, during the regular school day.

Orientation. The nature of the experiment, the equipment used, what was expected of the subject, the test used and what the experiment was designed to test was explained to all prospective subjects. Emphasis was placed on the fact that each subject was expected to be ready at the same time of the same day for six consecutive weeks and that he was expected to complete the program. On April 14 and 15 the actual testing procedure was explained as carefully as possible to each subject immediately after he had been selected. He was assigned a time to be tested and his age, weight and height were recorded.

Physical Conditions. Although temperature may affect maximal oxygen intake (16, 28, 56, 70) and heart rate (26, 60) the temperature was not controlled because there were no facilities for doing so in the field laboratory used. However, temperature was recorded at 9 a.m., 12 noon, 1 p.m. and at 3:45 p.m. of each experimental day.

Standardization of the Test Situation.

- (1) Each subject was tested at the same time of

day on the same day of the week for six consecutive weeks.

- (2) Because ingestion of food has a known effect on pulse rate and cardiac output (46, 62, 63), each subject was asked to eat at least one and one-half hours prior to the commencement of the test.
- (3) Subjects were advised not to smoke for at least one and one-half hours before the test.
- (4) All subjects were asked not to perform any strenuous activities for at least one hour before the test period, because of possible effect on pulse rate. Subjects were withdrawn from the Physical Education period and kept relatively inactive until tested.
- (5) Each subject was asked to be early for his appointment so that electrodes could be placed properly and he could rest for at least five minutes prior to the start of the test to allow a proper resting pulse rate to be taken in the sitting position.

Test Used and Its Administration. The test used was a slightly modified form of the bicycle ergometer test of working capacity developed by Sjöstrand (57) and modified by Wahlund (67), Kjellberg, Rudhe and Sjöstrand (42) and which has usually

been referred to as the Sjöstrand test. The test was conducted on a Monark Bicycle Ergometer of the von Döbeln type (Figure I) which utilizes a sinus balance to regulate the friction on a friction belt. The sinus balance was calibrated before the commencement of the test (Figure VI). In this test each subject was asked to pedal at a rate of 60 revolutions per minute for three consecutive six minute periods at variable work loads. Usually the first work load was 180 KPM/Min., the second and final work loads were adjusted on the basis of the heart rate response to the initial work load so that his final heart rate was close to 170 beats per minute.

As soon as the subject had arrived, electrocardiogram electrodes were secured and he was asked to sit and relax for about five minutes. Heart rate was recorded in the sitting position at the 4th and 5th minutes, after mounting the bicycle, and at one minute intervals throughout the test. Each minute the actual number of revolutions completed during that work load was recorded from the electrical counter. At the end of each six minute interval the work load was raised as quickly as possible to the next level.

The rate of pedalling was established by use of an electric metronome which offered an auditory stimulus at a set rate of 120 single beats per minute. This frequency ensured that 60 complete revolutions of the pedal occurred each minute.

Procedure. Before recording the pre-exercise pulse rates, the height of the bicycle seat was adjusted so that when the subject

was seated the sole of his foot, in the metatarsal arch region, was on the pedal. Since the bicycle seat post had previously been marked off at 1 cm. intervals, the seat position was then recorded. A slight bend at the knee joint remained, however a very slight extension resulted in a fully extended leg (Figure V). The handle bars were adjusted to the individual's preference.

When the subject started the test the brake belt was slack until he maintained the correct rate of pedalling. Then the desired work level was attained as quickly as possible by turning a handwheel which caused the friction belt to be placed under the required frictional force. This adjustment took but a few seconds. However the frictional forces produced heat on the belt, occasionally necessitating a further slight readjustment. The work load was checked at least each minute.

At one minute intervals the sixbeat heart rate was recorded on the electrocardiogram and the number of completed revolutions was also recorded. After six minutes the number of revolutions was recorded from the electrical counter while the work load was increased to the next work load level. The subject was not allowed to stop but continued pedalling at the prescribed rate. This procedure was repeated at the end of another six minutes. At the end of an additional six minutes the necessary records were taken and the subject was told to stop.

Each subject was required to take the Sjöstrand test on six consecutive occasions at intervals of one week. The work

loads for each subject remained the same on each occasion. The test was administered by the investigator.

Equipment. The bicycle ergometer was of the von Döbeln type (47), manufactured by the Monark Company Limited of Sweden, on which the subject pedals against a friction belt operated by a weighing device called a sinus balance (Figure I). The bicycle ergometer was modified so that an electrical counter connected to the pedal gear recorded completed revolutions. Both seat and handlebars were adjustable.

Heart rates were recorded on a Sanborn VisoCardiette (model 100) with a paper speed of 25 mm/sec. (Figure II). In order to improve conduction some Sanborn Redux electrode paste was applied to the electrodes. The two chest electrodes were secured at the first intercostal space directly below each nipple and below the pectoralis major muscle. The ground was attached to the forehead (see Figure III for Placement of Electrodes and Figures IV and V for Attachment to ECG).

An electrical metronome giving an auditory stimulus which was set to 120 beats per minute stimulated the subject to pedal at a rate of 60 revolutions or complete cycles per minute.

A tenth of a second precision stop watch was used. A clinical type weigh scale with a device for measuring height was used to obtain height and weight. The necessary equipment,

including a thermometer and electrical revolutions counter, were transported to and from the field research laboratory by car.

Statistical Treatment.

The following variables were recorded:

- (a) Pre-exercise heart rates.
- (b) Heart rates at one minute intervals, during the test.
- (c) The actual number of revolutions per six minute work period.
- (d) The work loads.

The work load was corrected for the actual number of revolutions per minute (See Appendix D). Then the heart rate vs. work load was plotted for each subject and his work capacity was determined at a heart rate of 170 beats per minute by fitting a straight line to the three "points" using a regression analysis. Then when all six tests were completed on the subjects the six physical work capacities for each subject were punched on IBM cards, as were the odd-even and split-half means of work capacities; the improvement score; the average pre-exercise heart rates; the average pre-exercise heart rate immediately before commencement of the test; the heart rate just prior to the first test; the calculated Y-intercept i.e., heart rate at zero work load for the first test and the average at all calculated Y-intercepts. The project number assigned at the University of Alberta computing

Center was 705003 and utilized library deck G 2011 to compute: means, variances, standard deviations, sums of squares and cross products, simple correlation coefficients, and partial correlation coefficients of all variables. These data were used to give values to carry out an analysis of variance and a Duncan's New Multiple-Range test to determine if significant differences between means had occurred and if so, which were significantly different.



FIGURE I. Monark GCI Bicycle Ergometer.

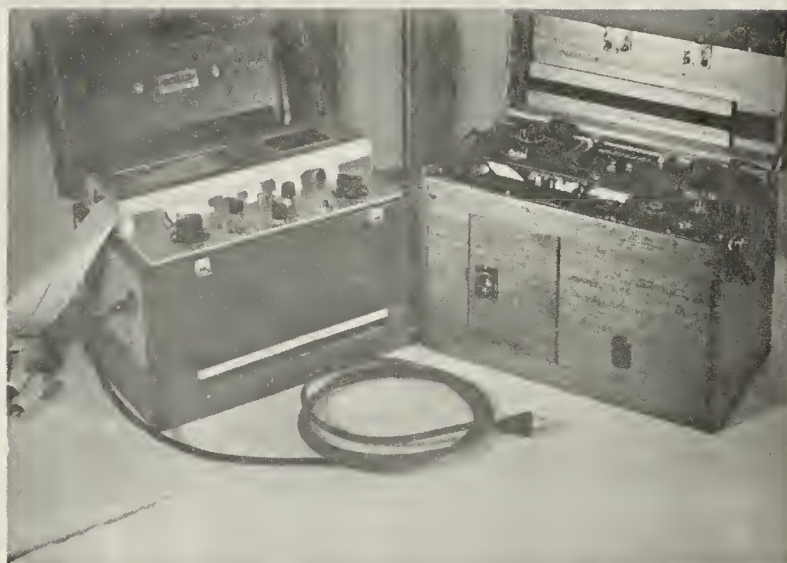


FIGURE II. Sanborne VisoCardiette (ECG model 51 and 100).



FIGURE III. Placement of ECG Electrodes on Subject.



FIGURE IV. Attachment to ECG.



FIGURE V. Subject on Bicycle Ergometer and Showing Attachment to ECG.

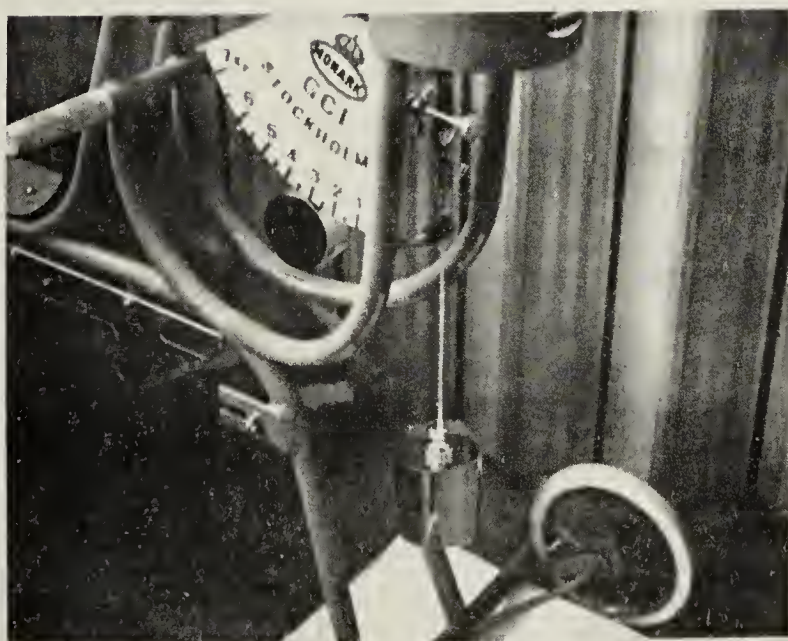


FIGURE VI. Calibration Technique for Monark Bicycle Ergometer Using 3 Kilogram Weight

CHAPTER IV

RESULTS AND DISCUSSION

Results

Means, Variances and Standard Deviations for the Work

Capacity Tests: Table I gives the means, variances and standard deviations for each of the six tests of physical work capacity.

It was noted that there was a general improvement in work capacity for the first four trials and a drop in the last two trials. It should also be noted that trial number 5 had a much smaller variance than the other trials.

TABLE I

MEANS, VARIANCES AND STANDARD DEVIATIONS FOR SIX
REPEATED TRIALS OF THE SJOSTRAND TEST ON 38 SUBJECTS
AT ONE WEEK INTERVALS
(Kilopond-Meters per Minute)

Statistic	Work Capacity Test Trial Number					
	1	2	3	4	5	6
Mean	943	973	994	1,039	1,018	1,003
Variance	45,030	40,701	46,237	41,357	33,344	46,334
Standard Deviation	212	202	215	203	183	215

Analysis of Variance of Physical Work Capacity Means:

A two-way analysis of variance for correlated samples (30 : 291) was used to test for significant differences between means of the six trials of work capacity. A summary of the results of the variance analysis appears in Table II.

Since there is a statistical difference in the means expressed in KPM/Min. at the $p = .01$ level, we must reject the null hypothesis that the population means are equal and accept the alternate hypothesis that there is a real difference between the means. In order to be significant at the .01 level the calculated F-ratio must be greater than 3.12 for 5 and 185 degrees of freedom and greater than 1.75 for 37 and 185 degrees of freedom.

Although significant differences between means have been demonstrated, it must be determined wherein this significance lies. For this purpose Duncan's New Multiple-Range test was employed. The results are tabulated in Table III. The results of this analysis indicate that there are significant differences between work capacities number 1 and 3, 1 and 4, 1 and 5, 1 and 6, 2 and 4, 2 and 5, and 3 and 4 at the 95% protection level. If the 99.5% protection level is selected, then significant differences occur between the following work capacity tests: 1 - 4, 1 - 5, 1 - 6, and 2 - 4.

TABLE II

ANALYSIS OF VARIANCE FOR THE SJOSTRAND TEST MEANS
 ADMINISTERED AT INTERVALS OF ONE WEEK FOR SIX WEEKS,
 N = 38, EXPRESSED IN KPM/MIN.

Source of Variation	Sum of Squares	df	Mean Square	F
Between Periods	218,829	5	43,765.8	8.75**
Between Subjects	8,435,497	37	227,986.4	45.57**
Interaction	925,511	185	5,002.8	
Total	9,579,837	227		

**Statistically significant at the .01
 level of confidence.

TABLE III

DUNCAN'S NEW MULTIPLE-RANGE TEST APPLIED TO THE
DIFFERENCES BETWEEN K = 6 TREATMENT MEANS EXPRESSED
IN KILOPOND-METERS PER MINUTE

Means	973	994	1,003	1,018	1,039	Least Significant R
943	30	51*	60**	75**	96**	R = 41.79
973		21	30	45*	66**	R = 43.54
994			9	24	45*	R = 44.73
1,003				15	36	R = 45.63
1,018					21	R = 46.34

*Statistically significant at the 95% protection level.

**Statistically significant at the 99.5% protection level.

Homogeneity of Variance: One of the assumptions necessary in the use of analysis of variance is that there is a homogeneity of variance. Upon applying the t-test of homoscedasticity of correlated samples (29 : 143), it was found that all except three comparisons were acceptable at the $p = .01$ level. The three comparisons for which there was a significantly greater variance at this level of confidence were between trials numbers 1 and 5, 3 and 5, and 5 and 6. It was noted that test number five occurred in all three of the comparisons which did not display homogeneity. It was also noted earlier (p. 34) that the variance of trial five was much smaller than the variance of the other five tests. Regardless of the lack of homogeneity for these three comparisons analysis of variance was used because Ferguson (29) has stated that moderate departures from homogeneity do not seriously affect the inferences made from the data.

Improvement in Physical Work Capacity: Figure VII gives a visual interpretation of the changes in mean work capacity over the six trials. To facilitate the interpretations and inferences which were made from the data, Figures VII, VIII, and IX are given together on one page. The abscissa in all cases represents the trial number. It should also be noted that the ordinate scale of Figure VII is abbreviated, i.e., it is not a full scale representation, and thus tends to exaggerate the differences between the means for the six trials.

The greatest raw improvement, with respect to trial one, occurred at trial four and represents an increase of 96 KPM/Min. Trials 5 and 6 means illustrate a decrement in work capacity compared to trial 4. This decrease may be accounted for by the influence of another factor (ambient temperature).

Mean Ambient Temperature During Work Capacity Tests:

Figure VIII illustrates the mean ambient temperatures recorded in the field laboratory during each of the six trials of work capacity. The mean ambient temperature for each of the trials was: 77.3, 77.4, 74.2, 73.5, 77.3, 80.1 degrees Fahrenheit respectively. It should be noted that the mean ambient temperature was approximately the same for trial numbers 1, 2 and 5; was lower for trials 3 and 4; and was higher for trial 6.

Mean Pre-exercise Heart Rates for the Six Tests: The

mean pre-exercise heart rates for each trial are plotted in Figure IX. Each mean reflects the average of the two pre-exercise heart rate measures on all of the 38 subjects combined. These means were: 86.8, 81.6, 79.3, 79.1, 81.1, 85.0 beats per minute respectively.

Means, Standard Deviations and Ranges of Age, Height and

Weight: Table IV contains the calculated means, standard deviations and ranges of age, height and weight for the thirty-eight subjects used in the study.

FIGURE VII

MEAN PHYSICAL WORK CAPACITY, 38 SUBJECTS, vs. TRIAL NUMBER

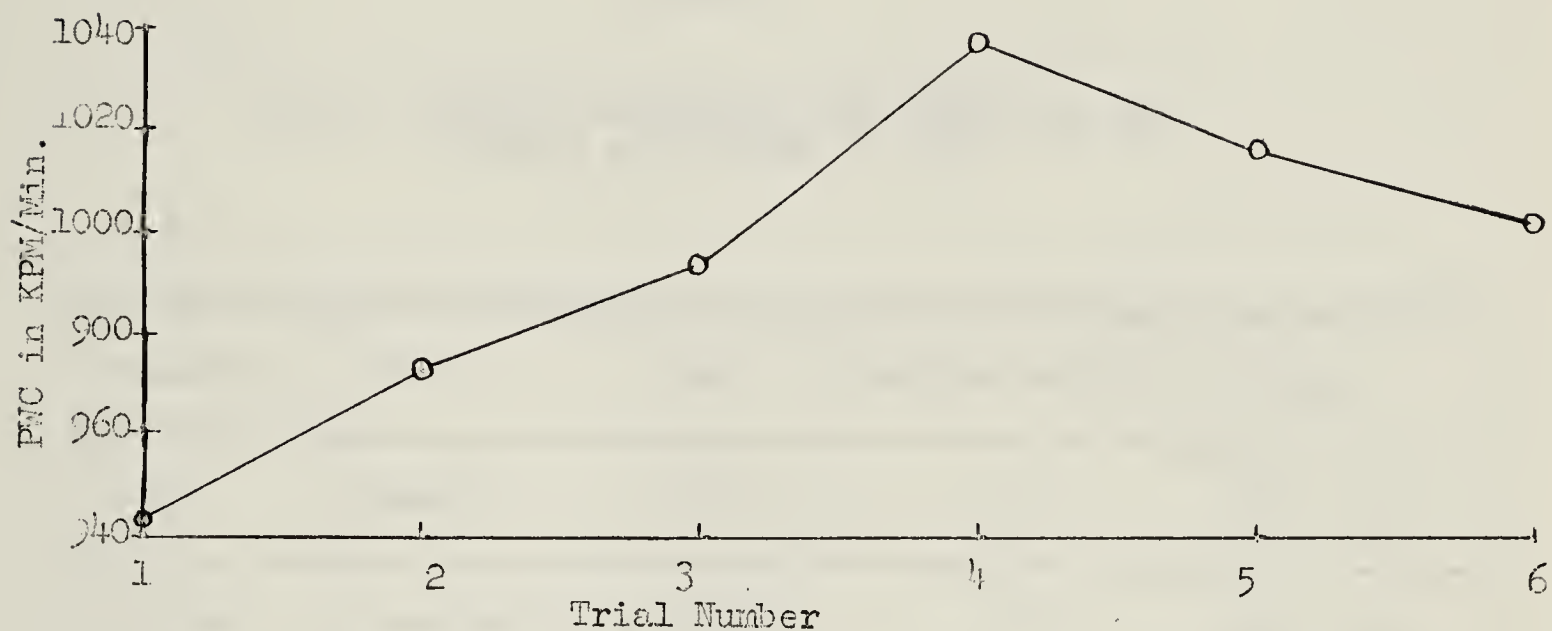


FIGURE VIII

MEAN AMBIENT TEMPERATURE vs. TRIAL NUMBER

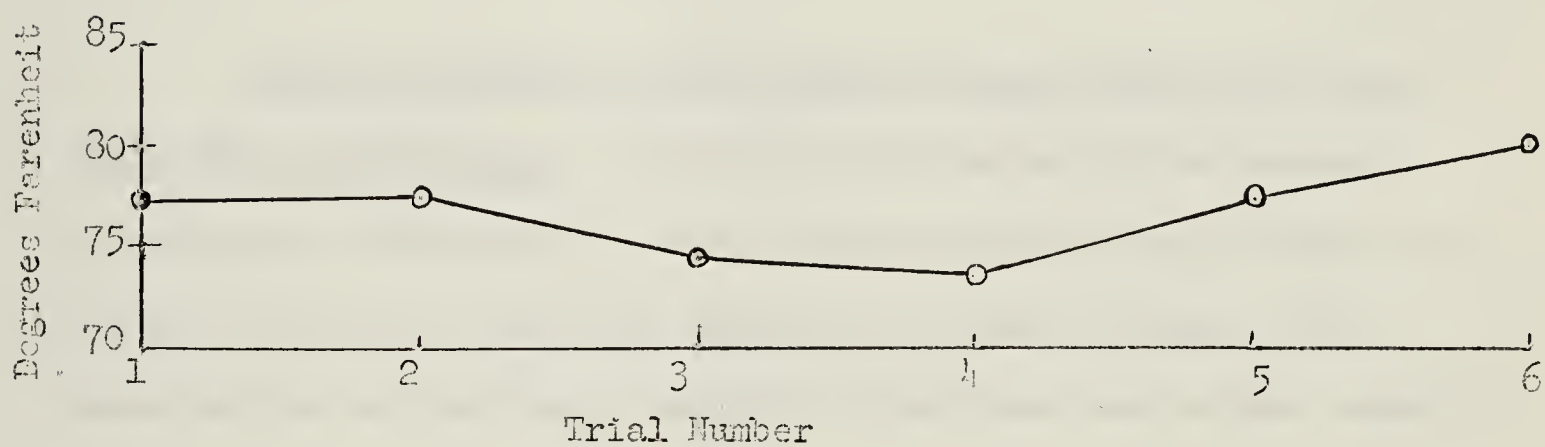


FIGURE IX

AVERAGE PRE-EXERCISE HEART RATE vs. TRIAL NUMBER

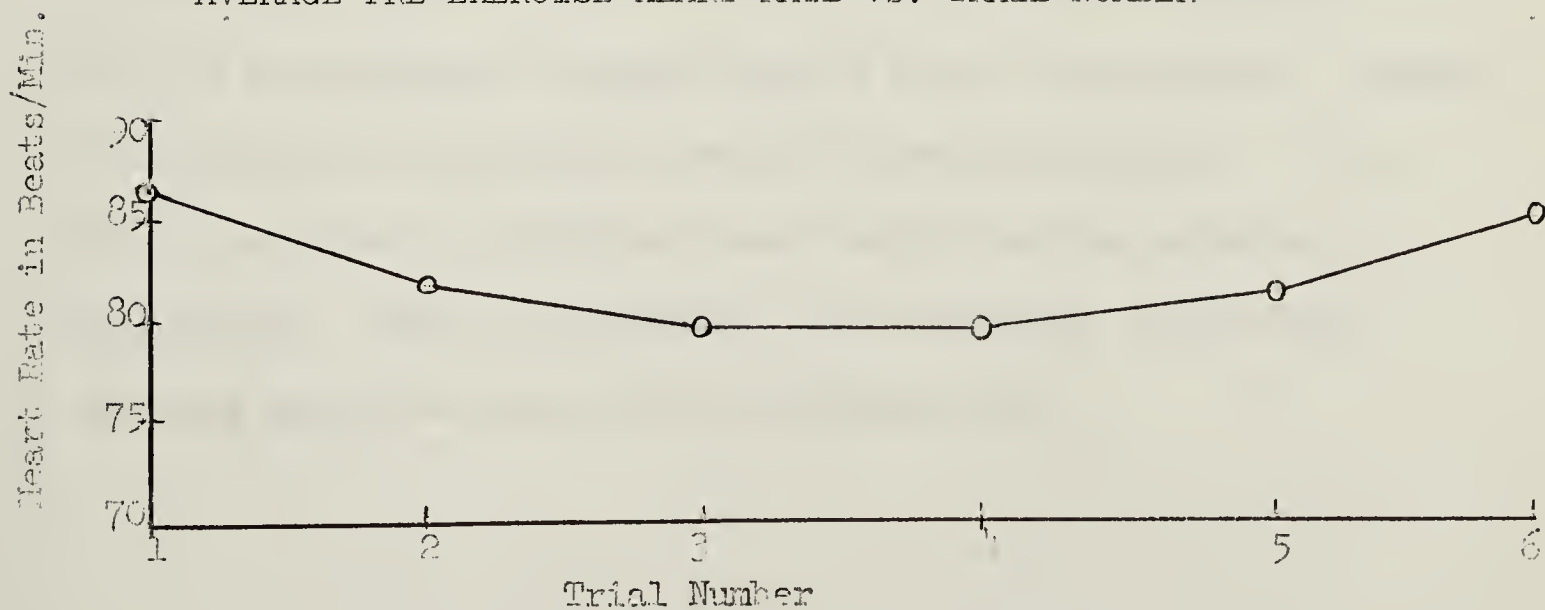


TABLE IV

MEANS, STANDARD DEVIATIONS AND RANGES IN AGE,
HEIGHT AND WEIGHT, N = 38

Parameter	Unit	Mean	Standard Deviation	Range
Age	Months	196.2	11.3	181 - 236
Height	Centimeters	175.2	5.6	163 - 189
Weight	Kilograms	67.4	8.7	44.9 - 88.9

Simple Correlation Coefficients of Age, Height and Weight with Each of the Trials: In Table V the Pearson Product-moment correlation coefficient for each of the parameters age, height and weight with each of the work capacity tests may be found. The correlations are generally small but significant and rather variable.

Inter-trial Correlation Coefficients: The correlation coefficients reported were obtained using a program developed for the International Business Machine Model 7040 computer. Pearson Product-moment correlations are used through this study. It is often convenient to interpret these coefficients as measures of reliability. Table VI summarizes the correlation coefficients obtained among the trials of the Sjöstrand test.

TABLE V

CORRELATION COEFFICIENTS* OF AGE, HEIGHT AND WEIGHT
WITH EACH WORK CAPACITY TEST

Parameter	Physical Work Capacity Test Number					
	1	2	3	4	5	6
Age	.341	.508	.282	.257	.305	.317
Height	.541	.480	.470	.399	.553	.530
Weight	.428	.521	.385	.441	.425	.435

* In order to be significant at the $p = .05$ and
 $p = .01$ levels $|r| \geq .320$ or $|r| \geq .413$ respectively.

TABLE VI

PEARSON PRODUCT-MOMENT CORRELATION COEFFICIENTS*
 FOR K = 6 TREATMENTS OF THE SJOSTRAND PHYSICAL
 WORK CAPACITY TEST EXPRESSED IN KILOPOND-METERS
 PER MINUTE, N = 38

Trial Number	Trial Number				
	2	3	4	5	6
1	.886	.930	.809	.921	.872
2		.894	.826	.893	.883
3			.841	.938	.904
4				.877	.857
5					.947

* All correlations are statistically significant at
 the $p = .01$ level.

Of the correlation coefficients obtained the lowest was .809 and the highest .947. Trial 1 correlates .886 with trial 2. This correlation may be interpreted as a test-retest reliability and is of the utmost importance in both the field and laboratory situation.

In any series of tests which demonstrates improvement over time it is desirable to express two other reliability

measures, viz., split-half reliability and odd-even reliability. The split-half reliability was .941; while the odd-even reliability was .947.

Inter-individual and Intra-individual Differences: Henry (35, 36) has proposed that a separation of intra-individual and inter-individual differences is possible on the basis of test-retest variances and that this will provide us with a better estimate of the test-retest reliability if an independent estimate of true error of measurement is available. The only estimate of measurement error available for this study was that of the calibration of the bicycle ergometer. It was found that the measurement error on this basis was approximately 1%. This does not, however, furnish a "true" picture of the variable error but rather an estimate of the constant error. It was decided, rather empirically, that 2% of the total variance would be a suitable estimate of variable measurement error for this study. A summary of the analysis is found in Table VII.

Initial and Final Work Capacity and Improvement: Improvement in work capacity may be operationally defined as the raw difference score between final and initial values of PWC_{170} . The correlation of initial work capacity score to improvement was found to be -.198. The correlation of final score to improvement was .303. Both were not significantly different from zero, since for 38 subjects the correlation must be .320 or greater or -.320

TABLE VII

AN ANALYSIS OF TEST-RETEST VARIANCES INTO INTER-INDIVIDUAL
AND INTRA-INDIVIDUAL VARIANCES AND THEIR INFLUENCE
ON RELIABILITY

Statistic	Work Capacity Tests Compared				
	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6
Total Variance	42,865	43,469	43,797	37,350.5	39,839
Between Test Day Variance	2,163.2	2,768	2,440	4,006.5	6,495
Estimated Measurement Error Variance	858.3	869.4	875.9	747.0	796.8
Intra-Individual Variance	1,306.2	1,898.6	1,564.1	3,259.5	5,698.2
Inter-Individual Variance	40,701.5	40,701	41,357	33,344	33,344
Test-retest Reliability	.886	.894	.841	.877	.947
Corrected Reliability	.950	.936	.944	.893	.837

or less at the $p = .05$ level of confidence. However there was a highly significant difference between these two correlations ($t = 2.718$, $p = .01$) as would be expected on the basis of the trial 1 - 6 correlation (.872), the analysis of variance and the Duncan's New Multiple-Range test results.

The Effect of Statistically Partialling Out Age, Height and Weight from Various Correlations: In many areas of research it has been useful to employ the statistical procedure of partial correlation. Table VIII gives the results of this procedure on the inter-trial correlations of the six work capacity tests holding age, height and weight constant in succession. The general result was a slight decrease in the size of the correlations.

TABLE VIII

CORRELATION COEFFICIENTS* BETWEEN SIX SUCCESSIVE
TRIALS OF THE SJOSTRAND TEST WITH AGE, HEIGHT
AND WEIGHT PARTIALED OUT

Parameter Partialled Out	Work Capacity Tests Compared				
	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6
Age	.881	.908	.829	.868	.941
Height	.850	.863	.808	.859	.925
Weight	.860	.880	.810	.849	.935

* All correlations are statistically significant at the .01 level

Table IX summarizes the results of partialling out the effect of age, height and weight from the split-half and odd-even reliabilities, as well as their effect on initial and final score correlations with improvement. In general partialling out these parameters slightly decreased the values of the split-half and odd-even reliabilities, while slightly increasing the values of the initial and final score correlations with improvement.

TABLE IX

AGE, HEIGHT AND WEIGHT PARTIALED OUT FROM SPLIT-HALF
RELIABILITY, ODD-EVEN RELIABILITY, INITIAL SCORE vs.
IMPROVEMENT SCORE CORRELATION AND FINAL SCORE vs.
IMPROVEMENT SCORE CORRELATION

Parameter Partialled Out	Correlation			
	Split-half	Odd-even	Initial-Improvement	Final-Improvement
Age	.937**	.942**	-.196	.334*
Height	.921**	.928**	-.243	.344*
Weight	.926**	.936**	-.217	.339*

* Statistically significant at the .05 level of confidence

($|r| \geq .320$).

** Statistically significant at the .01 level of confidence

($|r| \geq .413$).

Correlations of Various Pre-exercise Heart Rates with Work Capacity: Pre-exercise heart rates were recorded for each subject approximately one minute before the start of each trial and again approximately 10 seconds before commencing exercise. The intercept on the heart rate axis (ordinate) was recorded from the regression analysis used to calculate physical work capacity. Certain correlations of these parameters were desired. These correlations are given in Tables X and XI.

TABLE X

CORRELATIONS* OF VARIOUS MEAN ACTUAL PRE-EXERCISE
HEART RATES AND MEAN PREDICTED PRE-EXERCISE
HEART RATES FROM REGRESSION ANALYSIS
FOR 38 SUBJECTS

Parameter Number	Parameter	Parameter Number			
		2	3	4	5-Mean Y-Intercept Six Trials
1	Mean of First Trial Heart Rates Just Prior to Exercise	.815	.818	.796	.783
2	Mean Six Trial Heart Rates Just Prior to Exercise		.988	.610	.822
3	Mean of Both Pre-Exercise Heart Rates, Six Trials			.626	.835
4	Mean First Trial Y-Intercept				.786

*All correlations are significant at the .01 level of confidence.

TABLE XI

CORRELATIONS* OF EACH TRIAL (K = 6)
OF THE SJOSTRAND TEST WITH VARIOUS
PRE-EXERCISE HEART RATE PARAMETERS⁺

Parameter Number	Sjöstrand Test Trial Number					
	1	2	3	4	5	6
1	.416""	.368"	.407"	.296	.388"	.439""
2	.343"	.346"	.457""	.299	.359"	.398"
3	.322"	.315	.438""	.278	.329"	.372"
4	.425""	.415"	.392"	.401"	.389"	.420""
5	.337"	.360"	.394"	.260	.307	.352"

* All correlations reported are negative.

+ Parameter numbers are as in Table X.

" Statistically significant at the .05 level of confidence.

"" Statistically significant at the .01 level of confidence.

One other analysis was carried out on the mean actual pre-exercise heart rate, viz., to calculate the correlation coefficients between this parameter and each of the three work load heart rates for the first test only. The correlations resulting from this analysis were: .932, .668 and .0195 respectively. The first two correlations are significant at the $p = .01$ level of confidence; the third is not statistically different from zero.

Discussion

Currently the Research Committee of the Canadian Association for Health, Physical Education and Recreation are evaluating various measures of maximal oxygen consumption. Amongst the tests being evaluated are some predictive tests, i.e., tests which do not actually measure maximal oxygen uptake but rather predict its value from the known linear relationship of heart rate, work load and maximal oxygen consumption. Strictly speaking the Sjöstrand test only measures physical work capacity; however, several researchers (19, 20, 21, 52) have shown that the Sjöstrand test at a heart rate of 170 beats per min. gives values of the oxygen consumption which vary between 70 - 85% of the maximal oxygen consumption. Thus the Sjöstrand test might be used as a predictive test of maximal oxygen consumption.

One of the requisites of any test is that it be reliable. In part this experiment was planned to test the reliability of the Sjöstrand test of physical work capacity under a test-retest situation.

The other major question which was raised was, "Does work capacity improve with repeated testing?" This question does not differentiate between training effects and learning effects. Nor does this experiment differentiate between the two effects, but it is an attempt to record the results of improvement, if any, and the effect of repeated testing on the reliability of the Sjöstrand test.

The mean values of physical work capacity obtained in this study generally agree with those reported in the literature for the age group concerned. Bengtsson (12) reported a mean working capacity of 1,031.0 Kgm/min. for an age group of 15 - 20 years. Cumming and Cumming (19) cited their resulting mean for boys 16 years of age as 972 Kgm/M/min. The corresponding values obtained in this study for each of the successive tests were: 943, 973, 994, 1039, 1018, 1003 KPM/Min.

As may be seen from the successive means, as well as in Figure VII, there is a general improvement in physical work capacity from trials 1 to 4. There was a decrease in work capacity on trials 5 and 6. The analysis of variance indicated that some of the differences were significant.

This general improvement with repeated testing may be attributed to several factors, none of which may be specifically identified with certainty from this study. Firstly, the improvement may be due to a training effect. This implies that a subject may increase his cardio-respiratory efficiency through practice and

thus decrease his heart rate sufficiently at the same work loads to move the pulse/work curve to the right, i.e., increase his work capacity. There are several studies (16, 22, 43, 53, 69) which adequately illustrate that individuals undergoing regular physical training have increases in maximal oxygen consumption values. There is also the indirect evidence in the form that highly trained individuals have higher physical work capacities than normal subjects (7, 8).

Krogh and Linhard (44) have indicated that learning may take place on the bicycle in those areas where bicycle riding is not too popular. Astrand (6) occupies a position in sharp contrast to Krogh and Lindhard by stating that learning on the bicycle ergometer is negligible. On the basis of this study learning cannot be ruled out as a possible factor contributing to improvement in physical work capacity.

If Figures VII, VIII and IX are viewed together, two other contributing factors become evident. The mean ambient temperature for trials 1, 2 and 5 were 77.3, 77.4 and 77.3 degrees Fahrenheit respectively, but the mean pre-exercise heart rates dropped from 86.8 to 81.6 and 81.1 beats per minute on each of these successive occasions. The decrease in pre-exercise heart rate from test one to trial two is large and may be explained on the basis of "loss of apprehension". Thus these results would tend to agree with those of Taylor et al. (63) and Rowell et al. (56), while disagreeing with several other authors (7, 12, 47). But the further

very large increase in work capacity on trial 5 at virtually the same temperature and after several retests can no longer be explained on this basis and must be accounted for by some factor such as training or learning.

The mean ambient temperature was 74.2, 73.5, 77.3 and 80.1° F for trials 4 to 6 inclusive. Since temperature has a known effect on heart rate and maximal oxygen consumption (16, 26, 28, 56, 62, 63, 70), it is not surprising that the mean pre-exercise heart rates vary directly as the temperature, while physical work capacity varies inversely with temperature.

As was mentioned previously (p.38) one of the assumptions necessary in analysis of variance is homogeneity of variance. However, it was found that three of the comparisons did not meet this requirement, viz., trials 1 - 5, 3 - 5 and 5 - 6. These three comparisons of variance were significantly different at the $p = .01$ level as determined by the t-test for homogeneity of variance. All twelve other comparisons were non-significant. It was also pointed out that the three significant comparisons all involve trial 5 and that trial 5 has the smallest variance of the six trials. The only explanation for this large decrease in variance of trial 5 which can be put forward at this time is on the basis of differential individual reactions to increasing temperature, training and learning. This may be interpreted in the following fashion: those individuals who had the lower scores on trial 1 had most chance for improvement through training and

learning effects and although an increase in temperature would shift the pulse rate/work curve to the left, it would not be sufficient to offset the training-learning effect. But those individuals who were relatively well trained and/or skilled in bicycle riding would tend to have decreased work capacities, i.e., towards the mean because the temperature would be sufficient to override the training-learning effect. Thus there would be a decrease in dispersion about the mean. For trial 6 the temperature was likely sufficient to offset the training-learning effect in both groups.

Although homogeneity is generally a necessary condition prior to the use of analysis of variance and the attendant F-ratio test, it seems not to be a sufficient condition because Ferguson (29 : 240) has stated that, "Moderate departures from homogeneity should not seriously affect the inferences drawn from the data."

As may be seen in Table IV (p. 41) and in Appendix C, the subjects were rather similar with respect to age, height and weight. Yet the correlations of each of these parameters with the six work capacity tests were generally significant, even though small. Bengtsson (12) reports a correlation coefficient of .67 between age and heart rate of 170 beats per minute for males 15-20 years old. He also reports a correlation of .91 between weight and a minute pulse rate of 170 for this same group. Cumming and Cumming (19) report correlations of work

capacity of boys with height (.865) and with weight .897. Adams has participated in two studies utilizing the Sjöstrand test. The first was in California (2) using male and female subjects ages 6 - 14 years. For boys the correlations between working capacity and age was .79, with log weight .81 and log height .83. In another study Adams et al. (1) give correlations of .38 with age, .41 with log height and .40 with log weight for Swedish city school boys; for Swedish country boys these respective correlations were: .31, .47 and .51. The age range of the Swedish study was 10 - 12 years inclusive. The distinguishing feature of the last two studies quoted is that in the first the age range was 9 years, while in the second the age range was only 3 years. In the other two studies cited the age ranges were 6 years (12) and 11 years (19). It is apparent that as age range is increased, the correlations of age, height and weight with working capacity increases. The findings of this study substantiate those of Adams et al. (1) and may lend more credence to the hypothesis just put forward.

The correlation coefficients reports in Table VI may be interpreted as test-retest reliability coefficients for the Sjöstrand test. They range from .809 to .947 and all are highly significant at the .01 level.

However it is the first test-retest reliability coefficient which is pertinent to practical field work. This reliability was .886. In the field it is usually not possible or practical to

obtain two or more measures on the same test of subjects previously tested. It is desirable to have a measure of the reliability of the test prior to its use in the practical situation. Thus although many researchers have implied that the Sjöstrand test was reliable (1, 2, 12, 15, 19, 20, 21, 41, 42, 57, 61, 63, 67) only two (1, 20) have reported any data which might be construed as a test of reliability. Both Cumming and Danzinger (20) and Adams et al. (1) report test-retest situations extending over the summer holidays for school children; however they report their findings in such a way that no exact estimate of reliability can be made. For example Cumming and Danzinger report their findings on 19 male subjects who were retested in the following manner (20 : 202),

Of 19 boys studied, 5 showed no change, 7 showed and increase, and 7 showed a decrease in physical working capacity. There is no significant difference between the means of the working capacities observed in May and September.

It was one of the major objectives of this study to obtain test-retest reliability coefficients for the Sjöstrand test. This has been done and the Sjöstrand test has been found to be highly reliable.

In this study the split-half and odd-even reliability coefficients were very high, being .941 and .947 respectively. This would tend to indicate that although there was some improvement in test scores over the six trials, the improvement was consistent. These high reliabilities would also tend to confirm

the finding that the reliabilities between successive tests would be high. The successive reliabilities were: .886, .894, .841, .877 and .947.

An attempt was made to separate the inter-individual and the intra-individual differences on the basis of test-retest variances. Henry (35, 36) has also suggested that this would tend to give a better estimate of test-retest reliability. In this analysis it was necessary to make an estimate of the variable errors which may occur in measurement. It was decided, rather empirically, that 2% of the total variance was due to variable measurement error. This figure was decided upon on the basis that higher estimates tend to decrease the intra-individual variance to a point where it was a smaller factor than measurement error and Henry (36) has provided evidence that this is not the case.

The results of this analysis are partially in agreement with Henry's (35) in that the ratio of intra-individual differences to inter-individual differences are of approximately the same magnitude within each study, although the results herein reported are smaller than those reported by Henry. The corrected reliability coefficients given by Henry are either the same as, or higher than, the test-retest reliability coefficients which he had obtained. Using the same procedure in this study, the corrected reliability coefficients are generally increased substantially, while one was decreased substantially. However, it must be pointed out that the

results of this type of analysis employed in this study are rather suspect because of no adequate means of testing the variable measurement error.

Correlations of initial score of work capacity with improvement in work capacity was $-.198$; while the correlation of final score to improvement was $.303$. Neither of these correlations were significantly different from zero at the $.05$ level. But they were significantly different from each other ($t = 2.718$, $p = .01$) and the correlation between initial score (test 1) and final score (test 6) was high ($.872$). Woodrow (71, 72, 73), Cogan (17), Heese (32) and Henry (37, 38) have all pointed out the extremely variable correlations between improvement and either initial or final scores even though there is a high correlation between the initial score and the final score. The results reported agree with those found in the literature.

Partial correlations have not been reported to any great extent in the literature on the Sjöstrand test. The use of partial correlations has become more widespread in psychology and other sciences and has been found to be a useful research tool. The measure of correlation between the Sjöstrand test and maximal oxygen consumption reported by de Vries and Klafs (23) is a partial correlation, in which they partial out the affect of weight and surface area on one or more of the variables. In this study the effect of statistically partialling out age, height and

weight was to reduce the reliability coefficients between successive tests in all but one case. This reduction was generally small. It is suggested that this procedure would be useful when comparing different tests and when the dispersion of the variables to be partialled out is great. This was the case in the de Vries and Klafs study and in several other studies (11, 29) utilizing this technique. It is also suggested that this procedure is not necessary in research which wishes to establish reliability by use of the test-retest situation on the same subjects because these factors remain relatively constant for each subject, if the time interval between testing sessions is short. However it does give a baseline with which to compare reliabilities of various workers by tending to eliminate somewhat the differences in heterogeneity of the population.

Partialling out age, height and weight from the split-half and odd-even reliability coefficients also tends to decrease these coefficients slightly. The reason is likely the same as that given above. Partialling out these same factors from the correlations of improvement with both initial and final scores tends to increase the coefficients. In fact the correlations between improvement and final scores become significant at the $p = .05$ level. This may be explained on the basis that each of the variables when statistically held constant tends to decrease the differences between subjects on their initial or final score but not on the improvement score. Thus increased correlations would result.

From Table XI it is easy to see that measured pre-exercise heart rates correlate well with each other (.815 - .988), not as well with the mean first trial calculated intercept (.610 - .796), and quite well with the mean regression intercept for the six trials. All correlations were significant at the .01 level. These same parameters correlate negatively at low but significant levels ($p = .05$ or .01) in most cases with each of the work capacity tests. This would indicate that a low resting pulse rate would be indicative of a relatively high working capacity. The best indicator of working capacity from these parameters would be the mean of the first trial intercept, which correlates between .389 and .425, which are significant at the .05 level and the .01 level respectively.

The last analysis carried out in this study was between the mean actual pre-exercise heart rate and each of the three work load heart rates for the first test only. The correlations were .932, .668 and .0195 respectively. This agrees with general expectation since the first work load for all but three of the subjects was 180 KPM/Min. and the correlation between the two heart rates would be expected to be high. For the second work level more variability was introduced because of different work levels used and because of inter-individual differences in response to heavier work. The last work load would be expected to be even more variable on the basis of the pre-exercise heart rate for the same reasons. The last correlation was not significant but the first two were significant at the .01 level.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to investigate any effect which repeated performance of the Sjöstrand work capacity test might have on the reliability of the test as well as to chart any improvement which might occur. The null hypothesis used was that the successive work capacity means would be equal.

Of the original forty-eight male subjects selected from the volunteers from the physical education classes at Strathcona Composite High School, thirty-eight met the requirements of the experiment, that is, were tested on six successive occasions at intervals of one week. The Sjöstrand test was administered to each subject at one week intervals for six weeks at the same time of day on the same day of each week. The test itself was administered on a Monark Bicycle Ergometer and consisted of three uninterrupted progressively increasing work loads of six minutes each. Heart rate and revolutions completed were recorded at intervals of one minute throughout the test. Corrected work load was calculated using the factors obtained previously. A regression analysis was then used to determine the work capacity for each subject on each test. These work capacities were then punched onto IBM cards and Pearson Product-moment correlation coefficients and partial correlations were calculated by the use

of an IBM 7040 computer. To complete the statistical analysis an analysis of variance and Duncan's New Multiple-Range test were used.

The mean physical work capacities for the six tests were as follows: 943, 973, 994, 1039, 1018, 1003 kilopond-meters per minute. The statistical analysis indicated that there were statistically significant differences between the following trial numbers at the 99.5% protection level: 1 - 4, 1 - 5, 1 - 6, and 2 - 4; while at the 95% protection level the following additional trials had statistically significant differences: 1 - 3, 2 - 5, and 3 - 4.

The succeeding test-retest reliability coefficients were: .886, .894, .841, .877, and .947. Each was significantly greater than zero at the $p = .01$ level of confidence. It was pointed out that the first of these correlations was of most importance in the practical field situation. It was also noted that there was a significant difference between the means of trials 3 and 4 ($p = .05$).

A general trend of improvement occurred but it was not possible on the basis of this study to differentiate between learning, training or other effects which might cause the observed improvement. However, certain fluctuations in the mean physical work capacity values could be accounted for on the basis of apprehension and ambient temperature.

Conclusions

On the basis of the analysis used and within the limitations of this study the following conclusions appear to be justified:

1. For the population studied, the Sjöstrand test is a highly reliable measure of physical work capacity.
2. Improvement occurs upon repeated testing of subjects, but this improvement could not be differentiated into learning, training or other effects.
3. A feeling of apprehension decreased the value of the first test of work capacity.
4. Evidence was secured which supports the raising or lowering of work capacity because of changes in ambient temperature.
5. Low but significant correlations were generally obtained between work capacity and age, height and weight.
6. An attempt to separate intra-individual and inter-individual differences on the basis of test-retest variances were only partially successful because variable measurement error could not be adequately estimated.
7. The correlations between initial and final work capacity with raw improvement scores were not significantly different from zero; but they were significantly different from each other ($p = .01$).
8. The statistical partialling out of age, height and weight from the correlation coefficients tends to reduce these

coefficients slightly. This procedure is not recommended when the sample is relatively homogeneous or correlated and the time interval between tests is short.

9. Pre-exercise heart rates have low negative correlations with work capacity ($p = .05$).

10. The mean pre-exercise heart rate on the first Sjöstrand test correlated well with the first and second work load heart rates ($p = .01$) but produced a non-significant correlation with the third work load heart rate.

Recommendations

In the course of conducting this experiment several other associated areas of investigation which could fruitfully be investigated became apparent. The following studies are, therefore, recommended:

1. A study designed to differentiate between learning and training effects in improvement in physical work capacity as determined by the Sjöstrand test.

2. A study of a broad spectra of the population of Canada, male and female, to establish test-retest reliability and validity of the Sjöstrand test.

3. A longitudinal study of physical work capacity in a portion of the Canadian population to determine appropriate norms and which would also account for maturational factors.

4. A comparative study of the Sjöstrand test using three work loads and two work loads as well as utilizing abbreviated work periods.

5. The development of a nomogram for the Sjöstrand test to give predictive values of maximal oxygen consumption.

6. A series of cross-sectional studies on the population of Canada to establish appropriate work load levels and norms for different age groups.

7. A study of the Sjöstrand test administered on a variable work load type bicycle ergometer as compared to the test given on a constant work load type bicycle ergometer.

8. A study to determine the exact effect of ambient temperature on physical work capacity as determined by the Sjöstrand test.

9. A series of studies on emotional and motivational factors which might effect physical working capacity.

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APPENDICES

APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

Simple and Partial Correlation Coefficients.

Simple and partial correlations were calculated among various variables by use of IBM library program G 2011 on the IBM model 7040 computer.

Statement of Problem:

Given N sets of observations $(X_{i1}, X_{i2}, \dots, X_{ip})$, $i = 1, 2, \dots, N$, on p random variables. X_1, X_2, \dots, X_p , it is required to compute

$$(a) \text{ Means, } X_j = \frac{1}{N} \sum_{i=1}^N x_{ij}, \quad j = 1, 2, \dots, p$$

$$(b) \text{ Variances, } s_j^2 = \frac{1}{N} \left(\sum_{i=1}^N x_{ij} \right)^2, \quad j = 1, 2, \dots, p$$

$$(c) \text{ standard deviations, } S_j, \quad j = 1, 2, \dots, p$$

$$(d) \text{ correlation coefficients,}$$

$$r_{jk} = \frac{\frac{1}{N-1} \left[\sum_i x_{ij} x_{ik} - \frac{1}{N} \sum_i x_{ij} \sum_i x_{ik} \right]}{S_j S_k},$$

$$j = 1, 2, \dots, p$$

$$k = 1, 2, \dots, p$$

$$(e) \text{ partial correlations, } r_{jk.1} = \frac{r_{jk} - r_{j1} r_{k1}}{\sqrt{1 - r_{j1}^2} \sqrt{1 - r_{k1}^2}},$$

$$j = 1, 2, \dots, p$$

$$k = 1, 2, \dots, p$$

$$l = 1, 2, \dots, p$$

providing $j \neq k, j \neq 1, k \neq 1$.

(f) regression analysis $Y = \alpha + Bx$, $B = \frac{Sx^2}{S_{xy}}$, $\alpha = \bar{Y} - B\bar{x}$

(g) sums of squares, $\sum_i x_{ij}^2$, $j = 1, 2, \dots, p$

(1) sums of cross products $\sum_i x_{ij} x_{ik}$, $j = 1, 2, \dots, p$
 $k = 1, 2, \dots, p$

Significance of the Difference Between Two Correlation Coefficients for Correlated Samples.

To test the difference between any two correlations based on correlated samples a t value was calculated using the following formula (68 : 257):

$$t = \frac{(r_{12} - r_{13}) \sqrt{(N-3) (1 + r_{23})}}{\sqrt{2(1 - r_{12}^2 - r_{13}^2 - r_{23}^2 + 2r_{12} r_{13} r_{23})}}$$

The t was tested for significance with N-3 degrees of freedom.

Analysis of Variance.

An analysis of variance designed to test the significance of the difference between means obtained from correlated groups (two criteria of classification) was used in this study (30 : 291).

(see next page for Table)

Subject No.	Trial Number						$\sum_{r=1}^6 x_r$	$\sum_{r=1}^6 x_r^2$
	1	2	3	4	5	6		
2	811	896	861	1,254	1,088	1,078	5,988	6,120,202
3	911	907	911	904	891	847	5,371	4,810,997
4	925	951	958	1,061	1,051	1,031	5,977	5,971,073

49	739	682	778	1,041	835	784	4,859	4,012,091

$\sum_{i=1}^{49} x_i$	25,613	35,825	36,957	37,780	39,475	38,688		
$\sum_{i=1}^{49} x_i^2$	35,440,525	37,448,565	39,272,058	42,537,445	40,622,168	39,978,806	$\sum_{r=1}^6 x_r^2 =$	235,299,567

A. Sum of Squares

$$1. \text{ Correction. } CT = \frac{(\sum X)^2}{N} = \frac{(226,857)^2}{228} - 225,719,730$$

2. Total Sum of Squares About the General Mean.

$$SS_{\text{total}} = (811^2 + 911^2 + \dots + 784^2) - 225,719,730$$

$$= 235,299,567 - 225,719,730 = 9,579,837$$

3. Sum of Squares Between the Means of Tests.

$$SS_{\text{trials}} = (25,613)^2 + (35,825)^2 + \dots + (38,688)^2$$

$$- C.T. = 225,938,559 - 225,719,730 = 218,829$$

4. Sum of Squares Among the Means of Subjects.

$$SS_{\text{subjects}} = (5,988)^2 + (5,371)^2 + \dots + (4,859)^2 / 6$$

$$- C.T. = 234,155,227 - 225,719,730 = 8,435,497$$

5. Interaction Sum of Squares.

$$SS_{\text{int.}} = SS_t - (SS_{\text{subjects}} + SS_{\text{trials}})$$

$$= 9,579,837 - (8,435,497 + 218,829)$$

$$= 925,511$$

B. Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Between Tests	218,829	$C - 1 = 6 - 1 = 5$	43,765.8	8.75
Between Subjects	8,435,487	$R - 1 = 38 - 1 = 37$	227,986.4	45.57
Interaction	925,511	$(R-1)(C-1)=37 \times 5=185$	5,002.8	
Total	9,579,837	227		

Tests		Subjects	
Degrees of Freedom	= 5/185	Degrees of Freedom	= 37/185
F at .05	= 2.26	F at .05	= 1.47
F at .01	= 3.12	F at .01	= 1.75

Duncan's New Multiple-Range Test

Duncan developed this test (64: 107) to permit comparisons of treatment means with each other.

$$S_{\bar{x}} = \sqrt{\frac{(\text{error mean square})}{r}}$$

Least Significant Ranges (R) (.05)

Value of p	2	3	4	5	6
Significant Studentized Ranges	3.643	3.796	3.900	3.978	4.040
$R_p = (S_{\bar{x}} \text{ SSR}) =$ Least Significant Range	41.79	43.54	44.73	45.63	46.34

Rank of Means KPM/min.

943, 973, 994, 1003, 1018, 1039

Method of Testing the Difference

Largest - Smallest = 1039 - 943 = 96 41.79 significant

Largest - Second Smallest = 1039 - 973 = 66 43.54 significant

Second Smallest - Smallest = 973 - 943 = 30 41.79 not significant

Significance of the Difference Between Two Means for Correlated Samples

$$s_D^2 = \frac{\sum D^2}{N-1} - \bar{D}^2$$

$$s_D^2 = \frac{s_D^2}{N}$$

$$t = \frac{\bar{D}}{s_D} = \frac{\bar{D}}{\sqrt{\frac{s_D^2}{N}}}$$

degrees of freedom = N-1

Standard Deviation

$$s = \sqrt{\frac{\sum X^2}{N} - \bar{X}^2}$$

Significance of a Correlation Coefficient

$$t = r \sqrt{\frac{N-2}{1-r^2}}$$

degrees of freedom = n-2

APPENDIX B

INDIVIDUAL CONSENT FORM

DATA SHEETS AND REGRESSION ANALYSIS FORM

CONSENT FORM

Strathcona Composite High School
and The University of Alberta
Edmonton, Alberta

We, _____, are the parents
or guardians of _____ and we hereby
give our consent for our son to take part in a bicycle ergometer
study of physical working capacity. We understand that our son
has undergone a medical examination by a medical doctor at the
start of this school year and was, on the basis of his report,
allowed to take part in all sports and athletics offered at
Strathcona Composite High School. We further understand that
the test of physical working capacity is less strenuous than many
of the athletics in which our son would normally participate.

Signed this _____ day of _____ April, 1965.

Signature of parent or guardian

Address

Signature of parent or guardian

Address

NOTE: At least one parent or guardian must sign this consent form
before their son will be allowed to take part in this experiment.
Your son should have explained the nature of the experiment to
you. He has been told about the experiment and has shown a willing-
ness to participate.

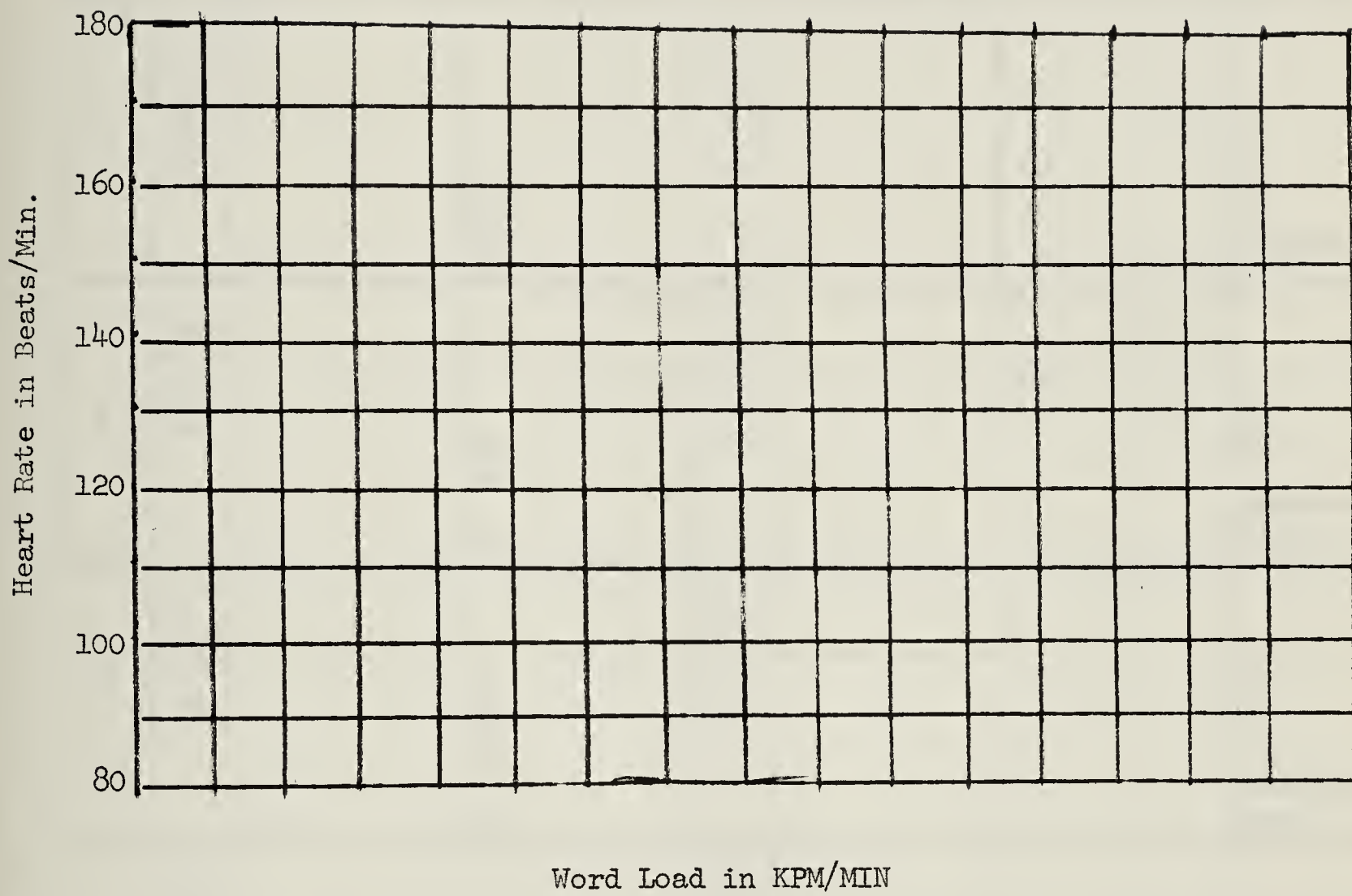
DATA SHEET

Subject No. _____ Trial No. _____ Name _____

Height _____ Weight _____ Age _____ Seat Posn. _____

Date _____ Testing Day _____ Time _____ Grade _____

Time	Work Load	Cycles Completed		Corrected W.L.	Heart Rate	
4th min. pre-ex.	None					
5th min. pre-ex.	None					
1 min./2 min.						
3 min./4 min.						
5 min./6 min.						
7 min./8 min.						
9 min./10 min.						
11 min./12 min.						
13 min./14 min.						
15 min./16 min.						
17 min./18 min.						



REGRESSION ANALYSIS FORM

Subject No. _____ Height _____ Weight _____ Age _____

TRIAL NO.		$X = W.L.$	X^2		$Y = H.R.$	Y^2	XY
1	_____			_____			
	_____			_____			
	_____			_____			
	\sum $\frac{1}{N} \sum$		\bar{X}^2 S_x^2	\sum $\frac{1}{N} \sum$			\sum $\frac{1}{N} \sum$ $\bar{X}\bar{Y}$ S_{xy}
		$b =$	$a =$				P.W.C.
2	_____			_____			
	_____			_____			
	_____			_____			
	\sum $\frac{1}{N} \sum$		\bar{X}^2 S_x^2	\sum $\frac{1}{N} \sum$			\sum $\frac{1}{N} \sum$ $\bar{X}\bar{Y}$ S_{xy}
		$b =$	$a =$				P.W.C.
3	_____			_____			
	_____			_____			
	_____			_____			
	\sum $\frac{1}{N} \sum$		\bar{X}^2 S_x^2	\sum $\frac{1}{N} \sum$			\sum $\frac{1}{N} \sum$ $\bar{X}\bar{Y}$ S_{xy}
		$b =$	$a =$				P.W.C.
4	_____			_____			
	_____			_____			
	_____			_____			
	\sum $\frac{1}{N} \sum$		\bar{X}^2 S_x^2	\sum $\frac{1}{N} \sum$			\sum $\frac{1}{N} \sum$ $\bar{X}\bar{Y}$ S_{xy}
		$b =$	$a =$				P.W.C.
5	_____			_____			
	_____			_____			
	_____			_____			
	\sum $\frac{1}{N} \sum$		\bar{X}^2 S_x^2	\sum $\frac{1}{N} \sum$			\sum $\frac{1}{N} \sum$ $\bar{X}\bar{Y}$ S_{xy}
		$b =$	$a =$				P.W.C.
6	_____			_____			
	_____			_____			
	_____			_____			
	\sum $\frac{1}{N} \sum$		\bar{X}^2 S_x^2	\sum $\frac{1}{N} \sum$			\sum $\frac{1}{N} \sum$ $\bar{X}\bar{Y}$ S_{xy}
		$b =$	$a =$				P.W.C.

APPENDIX C

RAW SCORES

INFORMATION PERTAINING TO INDIVIDUAL SUBJECTS
PHYSICAL CHARACTERISTICS

Subject Number	Age in Months	Height in cm.	Weight (Kgm)
2	196	180	64.0
3	192	173	64.9
4	187	180	71.9
5	182	172	64.0
6	202	170	70.4
7	200	171	64.1
8	209	165	60.5
9	209	189	80.6
10	193	179	68.0
11	183	176	68.9
12	194	178	75.3
13	208	175	65.3
14	207	177	67.1
15	211	174	62.6
16	196	173	88.9
17	191	188	75.3
18	200	178	69.9
19	208	181	72.1
20	194	176	73.5
21	236	178	88.0
22	184	175	67.6
23	188	178	65.3
24	191	177	60.3
25	189	178	65.6
30	194	165	58.6
33	189	164	51.7
35	190	171	59.5
38	207	175	79.8
40	219	173	71.7
41	181	178	61.7
42	194	170	57.2
43	192	175	64.6
44	184	163	44.9
45	194	173	74.9
46	187	181	67.6
47	194	175	59.9
48	194	180	67.6
49	187	173	67.3

Minute Heart Rates for each Subject Before and During Trial 1 in Beats per Minute

Pre-exer- cise Heart Rate			Exercise Heart Rate at Minute																	
Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	82	96	105	102	107	102	102	100	115	113	115	122	115	117	143	153	153	155	158	161
3	78	76	98	98	97	96	98	98	114	123	122	127	125	129	148	158	155	161	170	173
4	90	80	102	107	115	118	115	111	125	130	134	141	138	134	155	158	167	167	170	173
5	118	93	130	115	130	117	117	123	143	153	150	153	150	155	173	176	184	187	180	184
6	96	99	120	113	123	120	122	125	136	138	143	143	145	145	155	164	167	167	170	170
7	89	85	101	94	89	98	95	90	118	115	114	118	115	113	132	136	145	150	150	150
8	90	94	100	103	105	102	100	105	123	125	129	134	138	138	153	155	161	167	170	170
9	106	91	113	108	111	114	110	114	132	132	129	129	134	132	145	150	153	153	153	155
10	93	80	113	110	113	114	118	118	138	145	145	143	150	150	167	173	173	173	180	180
11	98	105	123	129	118	120	125	122	145	153	150	150	145	155	180	184	184	187	187	187
12	107	105	129	136	132	141	141	132	148	136	141	143	143	143	164	161	161	167	167	161
13	87	100	105	106	105	102	106	110	130	129	130	136	125	136	167	173	173	173	173	176
14	72	76	91	96	100	96	96	97	122	127	127	132	132	136	164	176	170	187	191	191
15	72	71	89	85	96	94	92	88	110	123	120	125	129	132	158	170	173	180	180	180
16	91	105	105	106	103	103	107	110	125	129	132	134	132	132	150	161	167	164	167	167
17	70	70	81	86	85	95	97	97	115	120	122	115	125	125	150	145	158	164	170	161
18	73	78	91	97	95	97	101	100	110	113	122	120	125	123	145	148	153	158	158	161
19	95	87	103	105	107	110	101	105	141	134	134	132	134	132	150	155	153	155	155	158
20	102	89	120	122	118	113	117	122	155	164	161	155	148	150	191	187	195	204	200	200
21	87	85	101	106	105	102	96	97	114	118	125	122	127	129	148	150	153	155	153	158
22	113	94	111	118	105	107	113	110	114	125	134	138	136	141	148	155	158	161	161	164
23	52	59	77	74	78	85	80	82	122	129	134	136	141	138	158	158	167	173	173	180
24	83	78	105	103	101	102	99	96	129	120	122	120	129	134	155	164	164	167	170	170
25	66	73	88	92	85	87	85	88	113	115	111	113	113	115	141	145	155	158	161	164

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Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	118	122	125	132	125	129	123	136	150	161	155	164	167	167	184	184	184	187	184	184
33	70	73	117	115	110	111	115	117	132	129	136	136	136	141	155	161	167	164	170	173
35	96	99	129	115	129	132	127	130	148	155	155	155	161	158	170	173	176	176	176	176
38	80	90	93	102	95	96	103	98	110	115	115	111	111	117	145	155	155	158	161	164
40	102	123	125	125	123	122	125	125	143	153	155	155	155	155	170	173	176	180	180	191
41	91	91	114	122	122	115	122	117	136	150	153	150	158	161	167	173	173	176	180	176
42	54	52	68	69	74	77	68	68	100	101	111	108	107	110	141	161	170	176	184	180
43	54	62	94	96	96	95	95	99	117	115	122	122	122	118	153	164	180	180	184	187
44	101	106	129	125	123	129	130	130	148	150	150	145	145	148	167	167	167	173	173	176
45	94	93	114	113	110	115	125	110	143	145	153	145	153	150	176	180	191	195	195	200
46	91	73	108	101	102	114	95	103	123	129	114	123	123	129	150	155	161	167	167	170
47	66	70	101	96	97	98	94	94	120	132	123	132	123	132	155	164	173	176	184	184
48	87	89	115	108	108	117	113	114	136	134	141	138	136	145	164	167	173	173	180	180
49	86	87	118	107	111	106	114	110	136	145	153	148	148	150	170	176	184	187	184	191

Pre-exer- cise He- art Rate		Exercise Heart Rate at Minute																			
		1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Sub. No.	1	2	103	106	105	100	102	108	115	117	122	115	114	115	117	136	145	145	148	155	155
2	75	76	97	92	89	94	94	91	117	123	123	125	129	132	129	153	161	167	170	170	170
3	78	80	97	96	98	94	98	102	115	125	123	127	132	127	127	153	158	161	161	167	167
4	75	76	90	103	111	99	115	108	125	125	134	134	141	145	138	161	167	170	170	170	170
5	84	68	105	106	102	108	107	105	125	125	129	129	134	136	134	153	155	155	158	155	161
6	68	76	98	98	91	89	91	93	123	123	129	129	125	123	129	143	148	155	158	161	164
7	86	83	105	105	98	100	107	98	125	125	129	129	129	132	130	141	153	155	161	161	161
8	94	100	105	110	105	105	108	107	127	127	145	145	145	148	148	141	148	150	155	155	161
9	64	85	115	110	111	111	113	111	141	141	145	148	145	150	148	167	173	173	180	180	161
10	106	98	123	123	125	122	122	127	145	145	150	148	145	150	148	167	170	176	180	180	180
11	88	98	132	129	136	136	136	132	150	145	150	148	145	141	148	167	170	180	180	180	167
12	94	87	113	115	111	110	115	113	134	134	145	148	141	141	155	167	167	167	167	167	167
13	73	87	99	102	100	103	102	106	122	122	125	130	132	130	161	167	170	176	176	176	173
14	70	64	93	86	84	83	88	88	105	105	110	111	113	115	145	155	164	167	173	173	180
15	79	80	102	110	103	101	106	101	123	123	125	125	125	127	145	155	155	155	161	161	176
16	64	56	80	85	93	81	90	87	111	111	111	111	111	115	141	155	155	155	161	161	161
17	74	71	84	91	82	87	81	88	108	108	107	111	111	114	145	148	145	153	155	155	158
18	80	74	85	96	80	82	87	91	125	125	125	115	117	125	141	145	143	155	155	155	158
19	92	83	110	107	115	113	110	105	153	153	161	164	167	167	150	155	155	155	161	161	161
20	96	88	94	100	102	98	98	105	105	125	125	127	129	129	187	191	195	195	195	195	195
21	111	94	110	108	108	107	110	100	123	123	130	117	117	115	155	134	138	141	150	150	145
22	49	52	89	84	87	95	89	95	129	129	132	134	134	130	150	155	155	164	161	161	167
23	87	86	102	101	103	100	110	113	132	129	132	129	132	136	161	164	170	173	176	176	173
24	69	73	101	94	101	93	94	98	117	117	113	117	117	145	161	164	170	167	170	170	173
25															143	145	148	150	158	158	161

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Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	99	110	127	125	123	127	132	125	141	161	155	161	164	167	173	176	180	184	184	184
33	61	71	91	102	96	106	105	110	127	132	125	127	138	136	161	167	167	173	180	176
35	70	80	98	97	101	108	108	110	127	138	143	141	145	148	155	161	161	158	155	161
38	76	79	88	83	90	87	84	85	105	107	107	107	110	113	134	141	143	145	148	148
40	105	98	113	113	113	107	108	113	134	138	141	141	141	143	155	164	164	167	164	164
41	96	90	95	111	111	108	117	107	132	136	145	145	145	145	155	158	164	167	170	170
42	61	61	79	71	71	73	78	76	102	103	106	108	117	105	150	164	170	176	180	184
43	60	55	85	72	80	82	80	80	103	102	111	110	108	105	143	150	158	161	158	161
44	101	97	118	120	120	120	123	125	136	138	145	143	136	143	158	161	161	158	167	167
45	83	81	101	107	103	105	110	108	138	138	143	145	143	145	164	167	176	173	180	184
46	92	98	97	107	94	102	94	95	127	123	132	129	129	134	158	164	167	170	173	173
47	80	79	103	102	115	100	99	101	129	129	134	134	136	141	161	164	180	176	184	184
48	86	69	90	89	95	90	91	101	118	127	123	125	129	129	158	164	167	173	170	173
49	94	83	99	103	105	97	108	110	132	138	141	138	150	153	170	173	176	180	184	184

Minute Heart Rates for each Subject Before and During Trial 3 in Beats per Minute

Sub. No.	Pre-exercise Heart Rate	Exercise Heart Rate at Minute																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	96	99	97	94	97	98	98	110	110	113	108	115	113	136	141	145	148	153	158
3	74	87	88	90	87	91	91	113	115	120	122	122	132	143	153	167	167	173	170
4	89	102	103	105	108	107	102	123	134	130	134	136	138	153	155	161	167	164	167
5	70	83	91	91	93	102	108	127	127	123	130	125	129	155	155	161	161	164	164
6	68	110	105	97	102	90	120	120	130	120	132	132	132	145	150	150	150	150	153
7	74	98	87	88	85	99	122	118	122	118	129	123	123	141	148	150	155	158	161
8	76	95	93	100	99	98	117	118	113	113	113	115	125	141	153	155	158	158	161
9	77	84	84	86	83	86	108	93	93	93	113	115	110	129	134	141	143	145	143
10	76	107	108	98	94	105	141	143	141	141	141	145	150	167	173	170	173	180	180
11	71	102	99	113	120	118	132	136	141	141	143	145	150	167	173	176	180	180	180
12	87	118	115	115	122	122	132	132	134	125	132	125	129	150	155	155	158	161	164
13	82	103	100	106	100	103	130	130	132	136	132	130	132	129	155	155	158	167	167
14	80	103	98	91	97	99	129	129	130	125	123	125	125	164	173	173	180	180	184
15	69	77	65	78	78	76	92	107	105	136	111	114	118	143	155	161	167	170	173
16	76	107	101	106	113	110	120	120	125	136	129	125	125	148	148	155	161	161	161
17	43	86	74	78	85	82	99	106	127	127	111	107	106	138	141	138	148	150	153
18	74	100	100	102	100	97	117	122	110	123	118	127	127	145	145	153	150	155	161
19	56	68	76	71	79	70	103	106	106	102	108	111	107	136	136	138	145	148	150
20	94	113	103	115	110	125	150	150	167	167	164	167	170	187	187	191	195	195	191
21	107	107	110	108	110	113	129	132	134	134	134	132	136	145	150	155	158	158	158
22	102	101	106	102	102	102	125	125	136	134	141	136	136	155	155	161	158	164	164
23	60	84	83	93	98	102	132	132	130	130	141	141	136	155	161	164	170	170	170
24	69	88	101	98	100	89	125	125	129	123	129	129	129	155	161	155	161	161	164
25	59	76	83	84	87	84	105	105	111	102	111	113	110	136	143	148	150	150	153

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Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	110	98	118	129	127	123	118	117	143	150	155	158	161	167	176	180	180	184	184	184
33	80	77	105	100	107	107	111	107	127	132	130	129	132	134	161	167	170	176	176	180
35	102	105	122	125	123	123	122	123	148	153	158	161	161	155	173	173	176	176	176	176
38	88	78	96	97	97	97	94	94	117	122	123	114	122	122	145	150	155	155	155	158
40	115	115	113	107	110	117	118	113	132	145	150	148	148	155	161	167	170	173	176	180
41	107	76	102	100	103	101	113	113	134	141	141	148	153	158	167	173	180	176	180	180
42	54	60	71	73	73	70	72	67	103	105	103	97	103	107	145	167	167	173	176	180
43	52	52	76	71	76	74	67	71	92	97	102	106	102	107	129	141	153	153	155	150
44	73	82	97	97	94	97	94	90	110	113	113	113	113	113	130	141	143	148	145	143
45	90	83	107	105	103	92	105	99	136	138	143	145	145	148	161	173	170	184	176	180
46	78	83	88	92	100	81	100	103	118	115	123	122	115	125	148	148	158	161	164	170
47	70	80	102	94	99	97	94	100	115	122	127	136	122	132	161	173	173	180	180	184
48	81	78	92	98	92	98	93	101	120	122	120	122	122	122	155	167	170	173	176	176
49	87	90	117	110	118	118	122	122	141	148	143	148	145	150	167	167	176	176	180	180

Sub. No.	Pre-exer- cise He- art Rate		Exercise Heart Rate at Minute																	
	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	94	73	90	97	101	90	96	96	108	102	103	105	113	107	129	136	138	141	138	138
3	73	78	91	92	88	91	89	92	113	117	122	123	118	122	148	158	164	173	173	173
4	98	92	102	107	106	100	103	105	125	127	130	127	127	127	145	155	161	161	161	158
5	59	57	74	77	95	97	92	92	117	118	123	125	125	115	143	150	150	155	155	155
6	73	61	92	92	80	83	90	91	110	113	113	115	125	123	134	141	138	141	143	145
7	78	90	98	91	94	95	96	94	111	114	115	115	115	114	136	141	145	148	150	155
8	80	71	97	92	97	101	99	96	114	120	122	122	127	125	138	145	148	150	153	158
9	93	89	105	100	105	100	98	103	123	123	122	129	130	134	148	150	155	153	155	150
10	65	65	87	94	95	102	103	105	118	125	130	132	134	130	145	155	155	161	161	164
11	78	88	102	106	98	98	102	106	118	123	122	130	132	132	145	158	161	164	167	170
12	91	94	113	115	115	113	113	117	129	125	125	130	132	134	145	145	150	150	153	155
13	85	92	99	98	99	110	107	107	125	129	129	136	132	125	155	164	167	167	173	173
14	76	81	89	105	94	95	82	96	113	125	118	125	123	127	153	161	167	164	173	176
15	70	70	80	75	74	78	79	84	101	108	110	106	118	115	143	153	161	173	173	176
16	84	95	105	105	103	86	113	105	120	125	127	130	122	125	143	145	153	155	155	158
17	52	55	78	77	73	73	79	73	107	113	118	110	113	118	134	141	145	155	170	161
18	71	67	90	92	95	91	90	90	110	117	120	114	120	111	132	145	148	153	161	161
19	68	72	90	85	84	94	96	96	100	100	100	100	100	105	148	155	155	158	161	164
20	71	73	102	105	103	108	106	105	145	155	155	158	161	164	180	184	184	191	187	187
21	102	98	105	100	105	100	103	102	122	125	118	125	125	127	143	141	150	155	150	153
22	100	98	115	107	115	105	107	111	127	127	123	130	129	132	145	153	158	161	161	161
23	49	48	71	83	87	85	90	95	123	122	132	129	125	129	148	150	158	161	161	167
24	78	88	103	101	103	105	107	101	127	129	130	132	141	141	161	167	164	167	170	173
25	76	86	102	100	96	97	106	102	122	129	125	127	127	129	143	150	155	155	158	161

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Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	91	108	117	111	115	113	122	130	148	145	155	161	158	161	170	176	176	184	180	184
33	66	60	94	86	93	90	89	97	115	123	125	122	125	127	155	170	170	173	173	180
35	85	83	107	106	108	113	107	110	136	148	148	150	150	150	161	167	167	167	167	170
38	87	66	99	97	92	88	89	88	113	110	110	110	113	113	136	141	148	148	145	145
40	113	95	105	110	111	111	111	115	132	134	138	141	145	138	150	164	158	164	158	164
41	91	100	106	111	111	111	108	113	130	138	143	145	145	150	155	161	167	167	170	170
42	50	50	63	69	65	67	70	73	98	94	98	97	92	101	134	145	161	173	176	180
43	58	53	69	77	67	76	77	74	100	107	100	108	107	108	127	136	145	150	150	145
44	85	97	111	98	100	107	103	102	114	123	127	134	122	118	145	145	141	150	150	155
45	94	88	100	105	93	107	98	105	129	129	136	136	145	141	155	164	164	167	167	173
46	89	91	100	98	100	102	94	98	118	123	120	123	127	122	150	155	158	161	161	161
47	86	83	94	88	97	97	93	103	129	129	138	136	136	141	170	176	184	184	187	187
48	80	70	93	100	99	91	100	101	122	114	125	129	122	127	161	170	170	173	176	176
49	66	79	90	90	95	96	98	97	115	118	122	113	118	122	143	150	155	158	161	161

Minute Heart Rates for each Subject Before and During Trial 5 in Beats Per Minute

Pre-exer- cise He- art Rate			Exercise Heart Rate at Minute																	
Sub No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	100	88	103	90	95	99	99	99	113	107	108	110	101	110	136	138	138	136	145	145
3	76	75	90	87	90	87	88	89	108	117	117	125	125	125	148	155	164	167	173	176
4	84	78	102	98	96	96	101	101	118	123	123	132	129	132	150	150	155	158	155	158
5	65	66	102	94	102	98	90	98	115	117	127	130	125	130	153	155	155	158	164	164
6	63	69	97	97	106	98	99	102	114	115	120	129	122	127	147	148	145	150	150	155
7	74	70	88	88	83	83	89	90	110	108	111	115	111	117	132	141	143	150	155	158
8	85	93	99	91	100	102	102	103	117	125	132	129	125	130	145	153	155	155	158	161
9	96	100	96	98	99	94	105	100	117	118	120	118	123	119	136	138	141	148	150	145
10	73	83	103	108	108	107	113	114	143	148	143	145	148	150	161	170	170	170	173	173
11	98	87	110	110	118	117	113	108	125	136	136	134	138	138	158	161	164	167	170	173
12	89	99	114	106	113	115	115	113	123	123	123	125	123	125	148	150	153	153	158	158
13	91	86	103	100	103	100	101	101	123	127	120	125	130	125	150	161	161	164	167	167
14	86	90	102	102	96	94	106	102	122	123	125	129	129	120	155	161	167	170	173	176
15	72	70	83	76	73	79	75	73	107	107	107	102	114	113	145	155	164	173	173	176
16	98	94	106	103	100	105	105	99	118	125	123	123	130	129	145	150	150	153	155	158
17	60	60	86	89	80	78	92	88	110	110	105	113	114	118	143	153	150	161	150	155
18	71	74	91	102	90	101	101	99	117	118	125	125	125	122	136	148	150	153	155	155
19	77	76	95	95	92	96	97	100	118	122	125	127	130	125	148	140	150	161	161	161
20	80	83	103	105	106	113	103	107	138	141	150	155	153	158	176	184	184	187	187	191
21	97	98	105	103	98	105	102	102	118	123	120	122	122	122	138	141	145	148	150	155
22	96	101	115	108	111	115	113	111	129	130	130	136	132	132	150	153	155	155	155	161
23	69	66	97	89	98	94	88	94	123	132	136	134	134	132	155	155	161	164	173	170
24	87	80	103	97	113	110	107	110	129	129	130	132	132	132	161	161	161	170	164	167
25	88	78	94	95	98	96	99	98	120	123	118	118	123	120	145	145	150	153	155	158

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Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	80	87	115	106	108	106	101	113	136	143	150	155	155	155	164	173	176	176	176	176
33	64	54	80	78	79	78	85	87	107	106	105	114	113	111	145	145	155	158	161	169
35	83	91	113	105	113	105	111	108	134	141	150	143	150	148	158	158	161	164	164	161
38	88	94	102	98	101	98	106	100	114	118	118	120	125	127	150	155	158	161	167	164
40	94	108	117	114	118	113	113	114	129	141	136	148	145	150	155	158	161	164	167	167
41	83	93	105	105	107	108	110	108	125	134	138	141	141	141	153	155	161	167	167	167
42	60	55	66	70	65	69	71	73	88	100	101	97	102	103	134	145	155	167	173	176
43	60	59	81	76	63	79	83	83	107	107	110	107	117	108	141	150	150	155	161	158
44	81	85	97	105	102	99	113	111	122	123	125	132	127	129	138	153	150	155	158	158
45	91	89	105	110	106	102	108	103	134	134	145	148	150	148	167	167	173	180	184	180
46	85	89	94	108	100	98	94	105	125	129	127	125	127	129	150	153	158	158	161	167
47	70	73	92	95	96	102	102	101	130	130	134	134	132	132	167	173	173	180	180	187
48	63	70	87	88	88	83	87	91	113	114	120	123	122	118	153	161	167	173	176	176
49	90	82	103	103	105	103	110	108	130	141	138	143	143	145	161	167	173	173	176	176

Minute Heart Rates for Each Subject Before and During Trial 6 in Beats Per Minute

Exercise Heart Rate at Minute																				
Pre-exer- cise He- art Rate	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	100	101	99	103	102	100	108	99	111	114	113	108	110	132	141	141	141	148	143	145
3	81	87	100	96	105	99	96	100	115	125	134	130	132	155	161	164	164	170	176	180
4	87	78	89	91	84	102	95	98	113	118	122	122	123	141	148	153	153	153	158	161
5	66	69	93	78	84	83	87	94	113	120	114	123	123	145	153	158	161	161	155	161
6	76	82	95	96	97	98	102	98	122	123	125	129	125	141	145	150	155	155	153	153
7	85	81	96	95	101	100	94	98	117	115	122	122	123	138	145	153	150	150	155	161
8	83	88	101	105	100	107	111	107	129	129	132	134	136	150	158	161	164	164	167	167
9	86	79	95	101	113	101	102	105	118	120	127	118	118	145	145	150	153	153	153	153
10	67	91	102	113	115	111	113	117	138	145	141	143	148	170	167	173	173	173	173	176
11	90	96	118	123	122	118	118	118	136	143	145	148	148	167	170	173	176	176	180	184
12	113	110	125	125	123	129	132	127	134	134	141	129	136	148	155	161	161	161	164	167
13	88	91	113	117	110	107	113	103	127	127	127	132	122	164	164	167	170	170	170	173
14	78	78	97	87	94	98	94	98	113	110	122	122	123	150	158	161	164	164	164	167
15	78	79	97	87	95	80	106	98	118	123	132	134	136	161	170	173	180	184	184	184
16	98	89	100	108	105	102	102	103	118	122	127	129	127	141	150	150	155	155	158	158
17	58	59	83	79	83	80	77	83	103	103	101	107	110	136	138	145	143	143	148	145
18	77	75	96	94	105	106	103	108	122	132	132	129	129	150	153	161	164	164	170	170
19	75	74	89	79	75	80	90	83	110	114	115	122	117	141	145	148	150	148	148	153
20	81	85	113	105	107	108	111	106	138	153	164	161	161	180	184	187	191	191	191	191
21	98	97	94	97	98	97	96	96	111	113	115	113	115	130	136	134	141	141	143	145
22	98	102	108	115	108	107	106	108	125	123	132	132	132	148	145	153	153	153	161	153
23	62	57	88	88	94	91	97	98	118	127	129	130	134	148	150	155	158	164	164	167
24	86	93	107	106	115	111	115	110	127	138	132	136	138	161	167	170	173	176	176	173
25	91	97	99	102	100	103	100	100	120	125	127	125	125	145	153	155	158	161	161	163

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Sub. No.	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	94	101	120	125	113	136	129	118	148	161	161	167	164	167	180	180	184	180	184	184
33	62	57	77	78	78	78	83	83	106	114	107	100	117	99	150	161	161	167	170	170
35	90	100	100	100	108	97	107	100	129	141	138	143	141	141	155	155	161	158	164	164
38	85	87	100	100	98	96	99	99	114	110	118	120	125	120	145	150	161	161	164	167
40	111	100	117	114	113	107	110	111	122	141	136	141	145	145	155	155	164	164	167	170
41	94	101	108	108	102	106	115	106	129	138	150	150	150	153	164	167	170	173	173	173
42	75	69	79	80	82	80	83	77	108	113	110	115	107	113	145	153	158	161	161	167
43	66	62	86	87	76	77	90	83	96	113	107	107	113	106	129	138	141	148	155	155
44	102	107	114	113	110	110	98	110	136	134	141	138	141	138	155	150	158	161	161	161
45	73	88	114	98	101	101	106	102	130	138	145	143	145	150	167	164	170	180	180	180
46	96	96	105	105	105	107	106	110	125	122	129	125	127	129	155	158	161	161	161	164
47	87	82	100	100	105	101	105	96	136	125	134	132	132	134	164	170	173	176	180	184
48	79	73	89	85	96	94	93	87	125	123	123	123	127	130	161	164	170	173	176	176
49	87	98	118	117	107	115	118	118	141	148	143	143	145	153	167	173	176	180	180	180

Heart Rate and Corrected Work Load at Each Work Level, Physical Work Capacity, and Ambient Temperature for Each Subject on Sjöstrand Test
Trial Number 1

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
2	101	174	116	356	160	712	811	77
3	98	179	127	534	171	905	911	77
4	113	185	136	541	171	920	925	78
5	120	177	153	546	182	915	764	78
6	123	181	145	549	170	910	919	78
7	93	180	114	531	150	840	1112	77
8	103	178	138	533	170	925	915	77
9	112	178	133	535	154	893	1199	77
10	118	359	150	716	180	1074	954	77
11	123	351	150	728	187	1137	941	77
12	136	356	143	538	164	893	1025	78
13	108	179	134	540	174	1092	1094	76
14	97	180	134	549	191	1104	898	76
15	90	178	130	552	180	1125	1006	78
16	108	180	132	551	167	915	978	78
17	97	180	125	561	165	945	1024	78
18	100	178	124	534	159	890	1041	78
19	103	177	133	722	156	1256	1519	77
20	119	175	149	720	200	1122	839	77
21	97	179	128	546	155	935	1113	78
22	111	179	138	537	162	895	1000	78
23	81	175	139	690	176	1074	1005	78
24	98	180	132	554	170	945	999	79
25	87	179	114	561	162	1158	1274	76

continued on next page

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM.Min	Ambient Temperature °F
30	129	179	167	554	184	754	601	80
33	116	179	139	356	171	712	693	76
35	129	180	159	538	176	716	645	81
38	100	182	114	539	162	1146	1300	76
40	125	184	155	579	185	800	679	77
41	119	179	159	537	178	718	645	77
42	68	186	108	577	182	1208	1116	77
43	97	194	120	588	185	1209	1076	77
44	130	180	146	359	174	539	522	76
45	117	182	151	541	197	748	601	76
46	99	182	126	544	168	1092	1120	76
47	94	179	127	541	184	1092	958	77
48	114	185	140	546	180	966	864	77
49	112	180	149	540	187	900	739	77
							\bar{x} 943	77.31

Heart Rate and Corrected Work Load at Each Work Level, Physical Work Capacity, and Ambient Temperature for each Subject on Sjöstrand Test
Trial Number 2

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
2	105	180	116	360	155	728	896	77
3	93	180	130	538	170	900	907	77
4	100	177	127	542	167	885	951	77
5	112	179	141	537	170	888	892	77
6	106	177	135	535	158	892	1045	77
7	92	172	125	540	162	895	994	77
8	102	180	131	545	161	897	1018	77
9	107	181	127	545	158	910	1103	77
10	112	356	148	712	180	1071	960	78
11	124	356	149	712	180	1080	956	78
12	134	360	141	543	167	905	960	77
13	114	185	131	539	169	1080	1116	78
14	104	179	130	532	178	1074	988	78
15	88	181	115	546	175	1089	1063	76
16	103	179	128	531	161	893	1017	79
17	88	177	114	549	157	935	1099	79
18	85	181	121	543	157	908	1040	79
19	89	179	129	714	161	1239	1351	78
20	107	179	168	712	195	1074	785	78
21	102	184	116	543	141	865	1411	75
22	105	178	130	535	164	890	977	79
23	92	180	136	704	174	1092	1060	79
24	111	181	144	546	171	880	861	77
25	96	179	120	535	159	1056	1221	78

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Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
30	128	179	165	538	184	718	587	72
33	108	179	137	358	178	712	643	79
35	109	179	146	538	158	720	826	75
38	85	179	111	537	148	1077	1388	77
40	111	179	142	548	164	740	827	77
41	112	179	145	537	170	716	745	77
42	77	185	111	558	182	1235	1129	77
43	80	188	107	554	160	1104	1229	77
44	124	180	140	360	167	538	575	78
45	109	182	144	534	182	722	672	78
46	95	180	131	537	173	1080	1024	78
47	100	177	138	538	184	1080	911	78
48	96	177	129	545	172	1071	1048	78
49	109	177	151	537	164	928	682	78
							\bar{x} 973	77.4

Heart Rate and Corrected Work Load at Each Work Level, Physical Work Capacity, and Ambient Temperature for each Subject on Sjöstrand Test
Trial Number 3

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
2	98	180	114	361	156	722	861	77
3	90	180	127	540	171	905	911	72
4	108	179	137	543	166	910	958	77
5	98	180	127	540	164	900	984	77
6	105	182	132	542	151	905	1191	77
7	88	180	123	542	160	900	1002	77
8	98	179	125	538	160	900	1006	74
9	84	181	113	542	144	905	1221	74
10	100	362	147	724	180	1089	977	77
11	119	363	147	724	180	1089	979	77
12	122	360	130	542	163	905	1013	73
13	102	181	123	542	167	1089	1150	76
14	98	181	132	543	182	1098	972	76
15	77	180	116	543	172	1086	1057	73
16	111	181	125	539	161	900	1089	76
17	84	182	106	542	151	907	1157	76
18	99	181	127	538	158	908	1059	76
19	75	181	109	732	149	1267	1586	75
20	113	181	168	726	193	1089	797	75
21	111	180	134	538	158	910	1099	73
22	102	182	136	543	164	905	967	77
23	100	181	139	722	170	1086	1102	77
24	95	183	129	543	163	903	975	72
25	85	177	111	543	151	1074	1332	72

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Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
30	118	185	164	552	184	738	617	73
33	109	179	133	360	178	718	656	72
35	123	179	158	540	176	720	663	72
38	94	180	122	538	156	1083	1276	72
40	116	182	151	534	178	732	685	72
41	113	180	155	542	180	722	650	72
42	70	181	105	540	178	1265	1184	72
43	69	180	105	543	153	1083	1262	72
44	92	179	113	362	144	540	736	72
45	102	181	146	545	178	728	691	72
46	101	179	120	537	167	1074	1145	72
47	97	179	127	538	182	1074	961	73
48	97	183	122	534	176	1086	1031	73
49	122	179	148	535	180	895	778	73
							\bar{x} 994	74.2

Heart Rate and Corrected Work Load at Each Work Level, Physical Work Capacity, and Ambient Temperature for each Subject on Sjöstrand Test
Trial Number 4

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
2	96	178	110	358	138	714	1254	72
3	91	181	120	542	173	895	904	75
4	104	178	127	538	160	905	1061	73
5	92	179	120	537	155	890	1070	73
6	90	180	119	540	144	895	1235	73
7	95	180	115	540	152	900	1165	74
8	98	181	126	543	156	890	1066	76
9	101	182	132	540	153	900	1108	76
10	104	361	132	724	163	1086	1179	73
11	104	360	132	720	168	1080	1117	73
12	115	360	133	540	154	900	1111	76
13	107	181	129	542	173	1074	1058	73
14	94	181	125	544	174	1092	1047	73
15	82	180	116	543	175	1083	1048	78
16	109	180	124	540	157	897	1136	72
17	76	180	116	542	166	915	921	72
18	90	181	115	542	161	905	1030	72
19	96	180	124	720	163	1253	1405	73
20	105	181	162	728	187	1089	873	73
21	102	182	126	548	152	892	1155	79
22	109	182	130	548	161	910	1061	72
23	92	183	127	724	164	1080	1193	72
24	104	180	141	540	171	905	879	81
25	104	180	128	542	159	1074	1254	73

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/min	Ambient Temperature °F
30	126	181	160	543	182	726	618	76
33	93	179	126	358	177	716	662	73
35	109	182	150	540	168	720	730	75
38	88	182	113	546	145	1087	1481	71
40	113	180	142	540	161	720	835	72
41	111	182	147	542	170	723	745	72
42	71	183	97	540	178	1264	1208	72
43	76	180	108	537	148	1026	1275	72
44	103	181	120	360	153	542	683	72
45	102	180	143	546	170	726	748	72
46	96	182	125	540	161	1080	1193	72
47	98	181	138	541	187	1080	894	72
48	100	180	125	544	176	1069	1032	72
49	97	181	120	542	161	905	1041	72
							\bar{X} 1039	73.5

Heart Rate and Corrected Work Load at Each Work Level, Physical Work Capacity, and Ambient Temperature for each Subject on Sjöstrand Test
Trial Number 5

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
2	99	181	106	362	145	718	1088	75
3	89	180	124	540	175	905	891	79
4	101	180	130	540	158	900	1051	76
5	94	180	127	538	164	903	968	76
6	100	180	125	540	152	903	1158	76
7	90	180	114	540	157	900	1072	76
8	103	180	128	538	160	900	1045	81
9	102	180	121	543	148	905	1282	81
10	114	360	149	720	173	1080	1022	76
11	111	359	138	716	172	1080	1072	76
12	114	358	124	540	158	900	1059	81
13	101	180	127	540	167	1083	1113	78
14	104	180	125	543	175	1083	1043	78
15	74	180	113	542	175	1080	1036	77
16	102	180	122	540	157	905	1078	79
17	80	180	116	540	153	905	1080	79
18	100	180	124	538	155	895	1102	79
19	92	182	127	726	161	1256	1438	79
20	105	182	158	718	190	1086	858	79
21	102	180	122	538	152	897	1186	75
22	112	180	132	543	158	904	1101	81
23	91	181	133	716	171	1080	1091	81
24	109	183	132	543	166	895	965	77
25	98	173	122	538	156	1071	1290	77

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/min	Ambient Temperature °F
30	107	180	155	542	176	722	672	78
33	86	180	112	360	165	724	759	75
35	110	181	149	543	163	724	780	78
38	103	180	126	541	166	1083	1143	75
40	114	180	148	548	167	728	770	76
41	109	180	141	543	167	722	779	76
42	72	180	103	542	175	1264	1213	76
43	83	180	112	540	159	1050	1186	76
44	112	182	128	360	158	541	648	76
45	105	178	149	538	182	724	662	76
46	99	180	128	543	164	1086	1161	76
47	101	183	132	543	184	1086	944	76
48	89	184	120	546	176	1101	1047	76
49	109	181	144	543	176	908	835	76
							\bar{X} 1018	77.3

Heart Rate and Corrected Work Load at Each Work Level, Physical Work Capacity, and Ambient Temperature for each Subject on Sjöstrand Test
Trial Number 6

Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
2	104	180	109	360	144	720	1079	79
3	98	180	131	540	178	900	847	83
4	97	180	123	538	160	900	1031	80
5	90	180	123	540	158	895	1022	80
6	100	180	127	542	153	903	1135	80
7	96	180	123	538	158	903	1051	81
8	109	180	135	542	167	878	928	86
9	103	180	118	540	153	897	1194	86
10	115	361	145	722	174	1080	1027	81
11	118	360	148	720	182	1080	953	81
12	129	360	132	540	165	900	1063	87
13	108	180	127	540	172	1077	1066	77
14	96	180	123	540	166	1083	1144	77
15	102	180	135	540	184	1080	932	81
16	103	178	128	542	158	900	1066	75
17	80	181	109	542	146	905	1132	75
18	105	180	130	540	170	900	930	75
19	86	179	118	726	151	1256	1587	75
20	108	179	161	716	191	1080	841	75
21	96	181	114	540	144	900	1317	84
22	107	179	132	537	157	895	1074	77
23	98	180	132	716	166	1092	1179	77
24	112	182	139	542	174	897	867	86
25	100	182	126	543	162	1080	1203	78

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Sub. No.	HR ₁ Beats/Min	WL ₁ KPM/Min	HR ₂ Beats/Min	WL ₂ KPM/Min	HR ₃ Beats/Min	WL ₃ KPM/Min	PWC KPM/Min	Ambient Temperature °F
30	124	180	165	546	184	726	591	81
33	83	180	109	360	170	730	730	79
35	104	180	141	540	164	720	791	80
38	99	180	122	538	166	1080	1147	79
40	111	181	145	535	169	712	738	80
41	110	180	151	540	173	720	698	80
42	80	179	110	537	164	1253	1324	80
43	86	182	109	543	155	1026	1226	80
44	110	181	140	360	161	540	592	81
45	104	180	147	538	180	724	672	81
46	108	180	128	538	163	1086	1213	81
47	101	181	133	546	182	1086	950	82
48	90	184	128	540	176	1083	1008	82
49	118	180	149	545	180	905	784	82
							\bar{X} 1003	80.1

Mean Pre-Exercise Heart Rate and Mean of Last Two Heart
Rates at Each Work Load for Each Subject, Trial 1,
in Beats per Minute

Subject Number	Pre- exercise	WL ₁	WL ₂	WL ₃
2	89	101	116	160
3	77	98	127	171
4	85	113	136	172
5	106	120	153	182
6	97	123	145	170
7	87	93	114	150
8	92	103	138	170
9	99	112	133	154
10	87	118	150	180
11	102	124	150	187
12	106	137	143	164
13	94	108	134	174
14	74	97	134	191
15	72	90	130	180
16	98	108	132	167
17	70	97	125	165
18	76	100	124	159
19	91	103	133	156
20	96	120	149	200
21	86	97	128	155
22	99	111	138	162
23	56	81	139	176
24	81	98	132	170
25	70	87	114	162
30	120	129	167	184
33	72	116	139	171
35	98	129	159	176
38	85	100	114	162
40	113	125	155	185
41	91	119	159	178
42	53	68	108	182
43	58	97	120	185
44	104	130	146	174
45	94	117	151	197
46	82	99	126	168
47	68	94	127	184
48	88	114	140	180
49	87	112	149	187

Various Heart Rates for each Subject in Beats per Minute

Subject Number	Six Trial Heart Rate Means						First Trial	
	For Work Load 1	For Work Load 2	For Work Load 3	Y-inter-cept	Of Both Pre-exercise	Second Pre-exercise	Y-inter-cept	Second Pre-exercise
2	100	112	150	90	93	92	80	96
3	96	127	176	71	77	78	78	76
4	104	130	164	88	86	84	97	80
5	101	132	166	85	74	72	106	93
6	104	131	155	92	75	74	111	99
7	92	119	157	75	78	78	75	85
8	102	131	162	86	85	86	88	94
9	102	124	152	89	90	89	103	91
10	111	145	175	79	76	83	87	80
11	117	144	178	85	91	93	93	105
12	125	134	162	100	98	100	116	105
13	107	129	170	93	88	88	100	100
14	99	128	178	82	81	85	78	76
15	86	121	177	67	71	71	75	71
16	106	128	160	91	89	90	92	105
17	84	114	156	66	59	60	79	70
18	97	124	160	79	73	72	84	78
19	91	123	157	80	75	74	95	87
20	110	161	193	94	84	82	100	89
21	102	123	150	89	97	95	85	85
22	108	133	161	94	101	98	99	94
23	92	134	170	76	57	57	64	59
24	105	136	169	90	83	84	86	78
25	95	120	158	82	76	78	72	73

Subject Number	Six Trial Heart Rate Means						First Trial	
	For Work Load 1	For Work Load 2	For Work Load 3	Y-intercept	Of Both Pre-exercise	Second Pre-exercise	Y-intercept	Second Pre-exercise
30	122	163	182	102	102	104	113	122
33	98	126	173	76	66	65	100	73
35	114	151	168	96	90	93	114	99
38	75	118	157	82	83	82	84	90
40	115	147	171	96	107	107	106	123
41	112	150	173	92	93	92	99	91
42	73	106	177	54	58	58	45	52
43	82	110	160	65	58	57	75	62
44	112	131	160	87	93	96	106	106
45	107	147	182	80	87	87	88	93
46	100	126	166	86	88	88	85	73
47	99	133	184	82	77	78	75	70
48	98	127	176	81	77	75	97	89
49	111	144	178	96	86	87	93	87

APPENDIX D

CALIBRATION OF ERGOMETER, CALCULATION OF
WORK LOAD CORRECTION FACTORS AND THEIR USE

Calibration of the Bicycle Ergometer. The sinus balance was calibrated by means of a set of standard weights as follows:

(a) The brake drum was removed and the pendulum weight was set to zero.

(b) A one-half kilogram weight was attached to the spring as shown in Figure VI. Weights on the spring were regulated as required to bring the pendulum mark to the " $\frac{1}{2} - Kp$ " scale mark.

(c) This process was repeated at the "1 - Kp" and at each half scale marking up to and including the "7 - Kp" mark.

(d) Adjustments were made by use of the adjustment screw which altered the center of gravity of the sinus balance. In this way it was possible to obtain the least deviation about the readings.

The Calculation of Correction Factors. In order to correct for the actual work done, it was necessary to record the actual number of revolutions done by each subject throughout the experiment. If n = number of revolutions completed per minute at a work load, d = dial setting in KPM, and the distance which the rim of the brake wheel travels is 6 meters (5), then it is possible to compute the work output using the following formula:

$$\text{work output} = 6nd \text{ KPM/Min.} \quad [1]$$

A correction factor for any given work load may be obtained using formula [1] in the following manner:

if $n = 60$, $d = .5$ then work output = $6 \times 60 \times .5 =$
180 KPM/Min.

if $n = 59$, $d = .5$ then work output = $6 \times 59 \times .5 =$
177 KPM/Min.

then the difference in work output is the correction factor for that work load, i.e., $180 - 177 = 3$ KPM/Min. is the correction factor for a dial setting of .5 or a work load of 180 KPM/Min. This same procedure will give the correction factor for any work load. The use of the correction factor facilitates the calculation of the corrected work load.

Correcting the Work Load. In order to correct the work load for the actual number of revolutions completed, the following parameters must be known for that work level:

mean actual revolutions completed per minute = a ,

correction factor = $c.f.$,

work load = $w.l.$

Then the corrected work load ($c.w.l.$) may be obtained from the following formula:

$$c.w.l. = w.l. + c.f. (a - 60) \quad [2]$$

For example, if a subject pedals at an average rate over the six minutes of say 62 cycles per minute at a work load of 180 KPM/Min. and the correction factor is 3 KPM/Min. then the actual corrected work output is

$$\begin{aligned}\text{c.w.l.} &= 180 + 3 (62-60) \\ &= 180 + 6 \\ &= 186 \text{ KPM/Min.}\end{aligned}$$

If another subject at this same work load had a mean actual number of revolutions completed per minute of only 57 then his corrected work output would be

$$\begin{aligned}\text{c.w.l.} &= 180 + 3 (57-60) \\ &= 180 + 3 (- 3) \\ &= 180 - 9 \\ &= 171 \text{ KPM/Min.}\end{aligned}$$

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